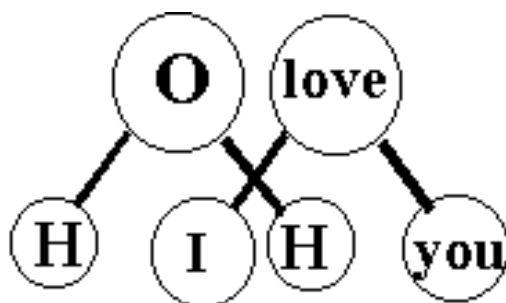


MOLECULES

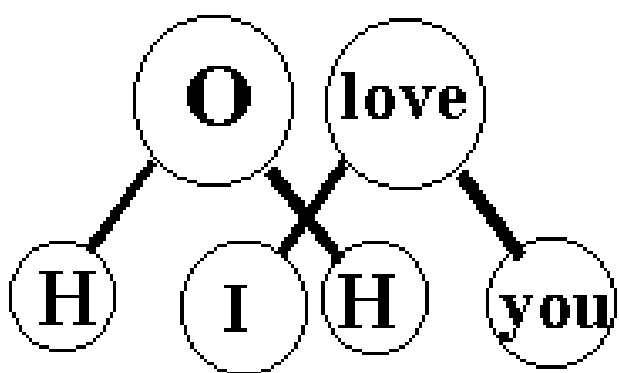
AND

THOUGHTS



Yuri Tarnopolsky

MOLECULES AND THOUGHTS



by Yuri Tarnopolsky

2018

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INTRODUCTION

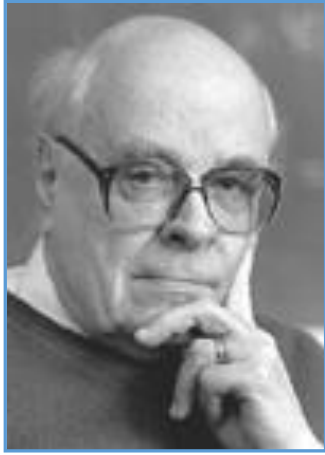
This file comprises the stages of my search for generalization of the chemical paradigm over real world systems of high and evolving complexity, including human mind and society.

Atoms selectively bonds with each other. Some bonds are stable, others weak or negative, which means mutual repulsion. Molecules can be stable, unstable, or practically impossible. As soon as various molecules are brought into contact, the bonds between atoms start a process of rearrangement into another set of molecules with lower total energy and higher stability. This is the core of chemical paradigm. Chemistry is about not just structures, but mainly chemical **events**, quite as our history is about **events** on planet Earth: events with beginning and end, consisting of smaller events. For a human observer, events are mostly known, but some are new, immediately turning into old. History displays the evanescent **novelty** of events but an extreme frugality with patterns. Patterns are variables of the algebra of natural complexity.

Unlike mathematical symbols and equations, chemical reaction runs in real time, sometimes instantaneous, sometimes over years. Chemical event at the moment of contact is in its initial state. The final state comes after some short, long, or indefinite time. Yet the speed of transformation depends on what is there between the initial and final states: the transition state. The latter is fleeting, unstable, irregular, turbulent, and against the rules. It is a barrier on the way to the final state and it requires additional energy to cross it over. It is the bottleneck of transformation and its stability defines the speed or probability of transformation. Physics is about processes and it does not care who pulls the trigger and who falls to the ground, while history is not about the bullet trajectory but about the victim of a murder and the shooter: it is about events.

Events in real world are similar to chemical events:

1. Fast revolution, political or technical, between two static periods.
2. American presidential campaign, for example between Obama and Trump terms.
3. Intellectual discovery between formulating a problem and coming to solution.
4. Correction of stock market or recession between two bull runs.
5. War between two periods of peace. Political crisis out of nowhere.
6. Process of decision-making after a package of new data.
7. Period between perception and understanding or recognizing a text or a face.
8. All processes of evolution are long-lasting sequences of events and so is individual human life.



Ulf Grenander,
1923-2016

Pattern Theory of Ulf Grenander provides a universal apparatus for representing states and events in real world and their reflections in human mind. It also provides a measure of energy or probability for configurations of atomic entities and of their regularity. It is the method of representing **everything** in terms of its interconnected constituents, i.e., figuratively, as points and lines, or, more realistically, as atoms and bonds. Its roots go back to atomism of Lucretius and structuralism.

Unlike symbols in mathematics, Grenander's generators, configurations, and *patterns* (classes of configurations) **possess** some properties of material phenomena, for example, probability, stability, and regularity, and yet are applicable to both fleeting thoughts and tenacious concepts in the mind. In a way, it is materialized thought.

Individual human life is also an event. It begins and it ends. Ulf Grenander and I completed our experimental "*History as Points and Lines*," but it was already too late to go together into pattern kinetics and **irregular** configurations. Whatever nonsense is there in my files, it is entirely my own. This yet undiscovered continent of knowledge still waits for somebody with worldwide interests, thirst for novelty, and reasonable distance from the final state.

Probably, my most significant personal realization, inspired by Pattern Theory, was the principle of natural (not artificial!) evolution of such very complex systems as life, mind ("intelligence"), and language from utterly simple beginnings:

Complexity naturally, i.e., without human engineering, evolves from simplicity by simple and **therefore probable** steps.

This principle shows why there is a chasm between natural and artificial intelligence and how it can be bridged with not yet predictable consequences. I would call the bridge Artificial Natural Intelligence, ANI. Until then, AI has enormous potential of arming humans against each other, while ANI might just expand humanity. Thus, our children are already natural products of artificial upbringing.

I believe that Pattern Theory builds for the first time the long-sought bridge between sciences and humanities. As somebody living in both elements, I express my amphibian personality in the style of my texts.

I offer my apology for my imperfect English. My life is but an event, too.

Sapienti satis.

Yuri Tarnopolsky

2018

Molecules and Thoughts

Pattern Complexity and Evolution in Chemical Systems and the Mind

Yuri Tarnopolsky

January, 2003

SUMMARY

Pattern Theory is representation of complexity in terms of atom-like blocks and bonds between them, similar to chemical structures. The paper attempts to look at chemistry from pattern perspective, “patternize” some general ideas of chemical kinetics, and import them into the pattern representation of the mind. In particular, it is intended to complement the recent *Patterns of Thought* by Ulf Grenander [1], which is the main frame of reference for this paper. The chemical concepts in question are: chemical complexity, transition state, catalysis, non-equilibrium systems, competition and selection of chemical species, and molecular evolution. Distinction is made between Ar-complexity (Aristotelian), which displays in the fixed generator space, and He-complexity (Heraclitean), which displays in the expanding generator space. The mind is regarded as an expanding configuration space, with the topology of a subset of the scale of sets (Bourbaki), where configurations compete for presence in consciousness. The concept is illustrated with computer simulations of building a He-system and spontaneous activity on some connectors.

Abbreviations:

LMS: Life, Mind, Society; **AI:** Artificial Intelligence; **NI:** Natural Intelligence; **Alife:** Artificial Life; **PT:** Pattern Theory; **Ar-System:** A system in a fixed generator space (Aristotelian); **He-System:** A system in a changing generator space (Heraclitean).

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Introduction

A lecturer tells some students to learn the phone-book by heart.

The mathematicians are baffled: 'By heart? You kidding?'

The physics-students ask: 'Why?'

The engineers sigh: 'Do we have to?'

The chemistry-students ask: 'Till next Monday?'

source: <http://www.talisman.org/~erlkonig/humour/science-jokes>

Pattern Theory (PT) is a mathematical representation of objects with large and incompressible complexity [2, 3, 4]. Some of the complex objects are static, as for example, telephone directory, others are natural and artificial dynamical systems, among them, life, mind, and society, for which the abbreviation LMS will be further used without distinction between natural and artificial. In the long run, a telephone directory evolves, too.

There is an obvious conceptual isomorphism between PT and chemistry. Both share the same principles of atomism, bonding, and transformation. Molecules, forms of life, thoughts, and social structures are typical and frequent illustrations of pattern analysis and synthesis in Ulf Grenander's works on Pattern Theory [2, 3, 4]. The parallel with chemistry is widely used in [1], for example:

Note the resemblance to chemistry: generators correspond to atoms, configurations (ideas) to molecules, and bonds to bonds ([1], 2.4: *Regularity of Mind States: Conformation of Ideas*).

A chemist can easily recognize in PT a kind of meta-chemistry. Molecules look and behave like configurations and they are configurations in the eye of a chemist at least superficially familiar with PT.

The similarity between the mind in *Patterns of Thoughts* [1] and a chemical system is especially conspicuous because of dynamic aspects. To an imaginative chemist, Ulf Grenander's representation of the mind may look like a Faustian apparatus, where the content is brewing in a blend of order and spontaneity, out of which Golem, instead of Homunculus, is about to jump out. To decide whether the parallel with chemistry is just a metaphor, we need to look at chemistry from the point of view of pattern meta-chemistry.

The science of chemistry is about 150 years old, but only during the last 70 years, which is comparable with the 50 years of Artificial Intelligence (AI), chemistry has developed a series of concepts, approaches, and subjects that give it the modern shape. A set of abstract ideas of chemical origin, known as Artificial Life [5], a mathematical discipline of significant generality, is among the developments of the last few decades.

Thinking about why Roomba [6], the recent "intelligent sweeper vac", the descendant of turtle CORA (Conditioned Reflex Analog) built by W. Grey Walter [7] in Great Britain in the 40's, still has a too limited intelligence for such a simple job as sweeping a floor, one may suggest that a little bit of life, however artificial, would not harm intelligence.

In this preliminary paper, written from the meta-chemical (i.e., pattern) perspective, the relevance of Artificial Life (Alife) for AI and NI is in the focus of attention. Some possible applications of generalized and hybridized pattern-chemical ideas to social sciences are also briefly considered.

While it may appear questionable what kind of input AI can have from chemistry, Ising model is an excellent example of importing a general idea from "hard science" to AI.

Ernst Ising, following ideas of Wilhelm Lenz, worked in the narrow area of ferromagnetism. Thinking on the reasons why his idea has spread over such vast areas, including

AI and Alife, a chemist could note that the model came from the area of condensed matter, i.e., structured systems, far removed from the traditional chaotic gas-like ensembles of independent particles. Condensed matter is an elementary “natural” case of probabilities on structures where interaction is defined on a meaningful topology. Ising’s initial object, a linear spin model, was, actually, a stochastic cellular automaton long before the birth of this term.

Life, mind, and society (LMS), apparently, belong to the same large class of condensed systems as ferromagnetics: the statistical ensemble is constrained by a structure, and this is what Pattern Theory is about. A cardinal difference between the condensed matter of physics and that of LMS is the non-equilibrium thermodynamics of the latter, combined with a quasi-solid medium for information storage (Erwin Schrödinger: “life is aperiodic crystal”). Besides, the variety of connectors in chemistry and LMS is exceptionally wide. From this point of view, some new areas of chemical experience, natural and artificial life in particular, can present a case for importing them, in a generalized pattern form, into pattern theory. As a sample of this import, genetic algorithms in pattern recognition can be mentioned [8]. The current trend is to map dynamical systems of AI and Alife onto the area of science of complexity as foundation.

Modern chemistry consists of a large number of separate fields and means different things for different people. In this paper, chemistry is meant to deal with molecular structure, addressing the following three problems:

- 1. Analysis:** Reconstruct an unknown configuration from a set of its transformations into known configurations.
- 2. Synthesis:** Given the initial and final configurations, design the shortest sequence of transformations from one to the other.
- 3. Reactivity:** Given an initial configuration C_1 at time t_1 , predict the most probable configuration C_2 at time t_2 .

Organic chemistry is in charge of all three problems, as well as of configurations of highest known complexity. It looks like a kind of a theater where some chapters of PT are played live.

The following Table lists parallels between chemistry and PT. In pattern symbolism, the concepts of transition state, catalysis, replication, and competitive selection would not be tied to

any specifically chemical substrate. It is an intent of this paper to fill, in a very general form, the empty blanks in the right column.

Table: Comparison of chemistry and PT

	Chemistry	Pattern Theory
1	Atoms	Generators
2	Bonds	Bond couples
3	Molecules	Configurations
4	Types and classes	Patterns
5	Reaction	Transformation
6	Concentration	Probability of configuration
7	Energy $E \sim \sum_i E_i$	Energy $E \sim \sum_i \log P_i$
8	Transition state	
9	Catalysis	
10	Replication	
11	Molecular Evolution	

It is important to forewarn that the description of chemistry in this paper, addressed to non-chemists, is very simplistic. Although this paper is a work of a chemist with life long interests in AI and NI, for whom comparison of molecules with thoughts has been quite natural, author's knowledge of mathematics, AI, and A-life is superficial and fragmentary. The paper is an invitation to a more professional bridge-building from the other bank.

1. Chemical complexity

Judging by the volume of publications, chemistry is the largest separate body of scientific knowledge. The combinatorial complexity of molecules is enormous. Chemistry studies transformations of configurations of unlimited size on the set of about one hundred basic generators of the Periodic Table. The most common generators have arity from 1 to 4. There is a cornucopia of connector graphs, among them cycles and bridged cycles that play the role of stable atom-like subconfigurations. There are also an infinite variety of text-like linear sequences.

The *Chemical Abstracts Registry* (CAS Registry) counts practically each known substance and chemical transformation. Their numbers are constantly growing. Figure 1.1 presents a typical report, constantly updated at [9]. On January 2, 2003, there were 20,809,353 organic and inorganic substances, 24,206,720 sequences, and 6,559,626 single- and multi-step reactions.

Each substance or transformation can be described in numerous publications and some of them are subjects of thousands of papers. The number of recorded chemical species, however, is but a small subspace of the entire chemical configuration space.

For comparison, all human thoughts, in the form of sequences of symbols, form yet uncounted but, probably, an equally staggering sequence space. Some mental configurations, for example, Ising model and Shakespeare's *Hamlet*, are subjects of countless publications in sciences and humanities respectively.

Chemical information is as incompressible and devoid of generality as a telephone directory. In addition, chemistry has a limitless craving for intimate details. Chemistry consists mostly of painstakingly described facts observed at certain conditions. The facts belong to two types: unitary structures and binary transformations. A novice in chemistry is often overwhelmed by the apparent absence of any rigorous theory of a mathematical nature, but this can be stated about works of Shakespeare, too.

**CAS is the leading provider of organic, inorganic,
and biosequence substance information.**

The Latest CAS Registry Number® and Substance Count

Date	Mon Mar 4 10:08:41 EST 2002
Count	19,417,310 organic and inorganic substances
	17,601,341 sequences
Total	37,018,651 chemical substance registrations
CAS RN	397841-96-2 is the most recent CAS Registry Number

Figure 1.1 Example of the CAS Registry count

Chemistry provides a good illustration to the distinction between configuration and image in PT, see [2], p. 52 and [3], p. 91. Chemical configuration is an abstraction. Its images are *conformations* with similarity transformation: **rotation around single bond**, Figure 1.2 A, wherever this rotation is possible. Chemists usually ignore conformations, unless they are relatively stable, and in biochemistry they often are.

Conformations, in turn, are abstractions, too. The images of a conformation have similarity transformation: **stretching and/or bending** (changing the distance and angle between bonds), Figures 1.2 C and B. The deformations are observable in molecular spectra. Mostly, but not exclusively, protein folding is a process of going through a sequence of conformations, complicated by various interactions.

At the level of configuration, chemistry can be as much reduced to statistical averages as *Hamlet* to the statistics of its word usage. This circumstance is often another source of distress for a student of chemistry with an analytical frame of mind, but a source of delight for dedicated chemists with a more romantic attitude to the world where it is individuality that matters.

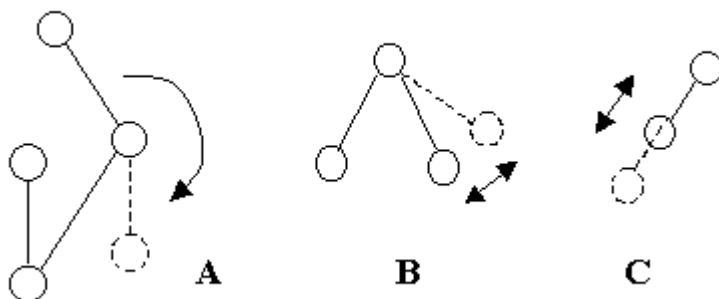


Figure 1.2 Bond deformations: A: Rotation, B: bending, C: stretching.

The type of combinatorial complexity that chemistry displays deserves a closer look.

There are two different ways toward a combinatorial explosion. The obvious way is expanding the base set. Another way was pointed to by Bourbaki in *Theory of Sets* [10, p. 259] and called *the scale of sets*.

In the following excerpt, $\mathcal{P}$, substituted for the original Gothic letter $\mathbf{P}$, denotes a set of subsets.

1. Given, for example, three *distinct* sets E, F, G, we may form other sets from them by taking their sets of subsets, or by forming the product of one of them by itself, or again by forming the product of two of them taken in a certain order. In this way we obtain *twelve* new sets. If we add these to the three original sets E, F, G, we may repeat the same operations on these fifteen sets, omitting those which give us sets already obtained; and so on. In general, any one of the sets obtained by this procedure (according to an explicit scheme) is said to belong to the *scale of sets on E, F, G as base*.

For example, let M, N, P be three sets of this scale, and let $R \{x, y, z\}$ be a relation between generic elements x, y, z of M, N, P , respectively. Then R defines a subset of $M \times N \times P$, hence (via a canonical correspondence) a subset of $(M \times N) \times P$, i.e., an element of $\mathcal{P}((M \times N) \times P)$.

Thus to give a *relation* between elements of several sets in the same scale is the same as to give an *element* of another set in the scale. Likewise, to give a mapping of M into N , for example, amounts (by considering the graph of this mapping) to giving a subset of $M \times N$, i.e., an element of $\mathcal{P}(M \times N)$, which is again a set in the scale. Finally, to give two elements (for example) of M amounts to giving a single element in the product set $M \times M$.

Thus being given a certain number of elements of sets in a scale, relations between generic elements of these sets, and mappings of subsets of certain of these sets into others, all comes down in the final analysis to being given a *single element* of one of the sets in the scale, [10], p. 259.

Here the combinatorial base set is constantly expanding because each new combination enters the set as a new element. Therefore, the number of initial elements can be quite small, as the following sequence, built of two symbols, but potentially infinite, illustrates:

$$\{(AB) (AB) [(AB) (AB)](BA)\} \{(AB) (AB) [(AB) (BA)](BA)\} \dots$$

The treatise by Bourbaki starts with describing mathematics as combinations (called *assemblies*) of *letters* and *signs* and fits prophetically well the structure of both chemical space and space of ideas. The letters correspond to generators and signs, including brackets, to bonds. Thus, not only mathematical formulas, but also sentences like “every finite division is a field” [10, p. 1] are listed as assemblies.

From the point of view of a chemist, the static chemical structures are no less *assemblies* than formulas and phrases because linearity of connector is not among Bourbaki's conditions and any connector graph is a *sign*.

It is a chemist's impression that both chemistry and PT go further by introducing measures on "assemblies" space, which leads to a thermodynamics of a kind.

The difference between the two ways of complexification, which could be referred to as conservative and progressive, is that in the conservative combinatorial space the elements do not have copies, while in the progressive one the elements have multiple entries into the combinations, which is the case with chemistry and ideas. New clusters of ideas get a new name or a new meaning of the old name and thus expand the base set recorded in dictionaries. This process is examined in detail in *Patterns of Thoughts* ([1], 3.3), where generalization creates macrogenerators and encapsulation adds a new idea to the envelope of the mind:

ENCAPSULATION : idea $\rightarrow$ env (MIND)

Note, that specialization can create new generators, too, when a new species of a taxonomic unit is discovered.

The process of generation of new ideas leads to progressive combinatorial explosion, unless there is a counteracting factor, which will be considered later. Without dissipating or depleting the envelope, combinatorial explosion might take over and paralyze the mind, with zero probability of retrieving any idea into content, which happens with Web sites during a massive "denial of service" attack, sometimes, spontaneously. While conservative combinatorial space is fully defined by the base set and the combinatorial operation, the progressive space must be generated in the process of evolution consisting of a series of choices. This is just a way to say that a progressive space has a *history*.

Whether we consider chemistry or AI, knowledge at any given moment has nothing to do with the history of the area. Nevertheless, the work of the collective mind has a historical dimension reflected in CAS registry, citation indexes, and in plain references to previous works that allow for reconstruction of history. In social structures, as well as in any individual human mind, however, history can have an enormous bearing on both popular mindset and individual character with its prejudices and motivations, Freud or no Freud.

The chemical configuration space is oppressively cumulative: each new structure remains on record. Against all odds, however, modern chemistry can successfully navigate its own real, not virtual, complexity with a modest number of tools of high power. This is why chemical experience might be relevant for handling other natural systems of towering complexity.

Whether it is fortunate or not that we still do not have the same power of simplification in LMS, is a matter of personal philosophy.

Since terms *conservative* and *progressive* are overloaded with connotations, to distinguish between two kinds of combinatorial complexity, terms Ar-complexity (Aristotelian) and He-complexity (Heraclitean) are suggested. The first one is defined by the fixed base set or, in terms of PT, fixed generator space, while the second one builds up as a mapping onto the scale of sets. In terms of PT, it would sound as expanding generator space.

It has always been among major scientific goals to work on well-defined structures, which is, probably, the main reason for the rift between sciences and humanities. He-complexity could be a way to mathematically accommodate history of individual life, biological species, ideas, and nations by reflecting the distinction between old and new.

According to Bourbaki's terminology, any scale of sets built according to explicit instructions, *belongs* to the scale of sets on a particular basis. Taking some liberties, we will use term *scale of sets* for this kind of a partial scale, too.

Chemistry serves as an example of He-complexity because almost every chemical structure can be combined with another and given a new name and a new CAS number, which would allow for tracing the evolution of chemical space. A similar kind of complexity can be found in the development of algorithms by combining subroutines into new standard blocks. Any block is always *younger* than its constituents and thus the evolutionary axis is established without the physically explicit variable of time.

Remarkably, Pattern Theory in its current state does not need any modification to accommodate both Ar- and He-systems. It is inherently fit to describe patterns of history, to which physical sciences have been traditionally blind.

A different example is the scientific citation space, where a point refers down to previous points and is referred down to in subsequent citations, which is similar to the *levels* along Ulf Grenander [1]. Notably, the citation space, is not a hierarchy in the sense any taxonomic space is: all citations are equal and refer to real works. The citation network is partially ordered and it establishes a direction of natural historical time.

One may wonder whether the gigantic molecules of DNA are also organized as the scale of sets, coding the phylogenesis of the species as well as the basics of ontogenesis.

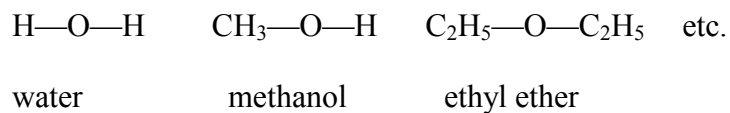
We return to this idea later because it seems to be of utmost importance for the structure of working mind.

2. Molecular patterns

It may look on the surface that chemistry lacks an explicit concept of pattern. Nevertheless, the concept of pattern is deeply ingrained into chemical thinking and is one of the most efficient ways to manage the unbearable burden of chemical complexity.

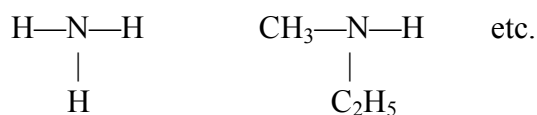
The initial ideas of chemistry about structure had a lot of pattern spirit. According to *theory of types* of Auguste Laurent (1807-1853), molecules were supposed to fall into certain structural patterns, called *types*, for example, of water and ammonia.

The type of water is $A-O-B$, where O is oxygen and A and B can be any combinations of atoms, among them:



Here the similarity transformation is substitution of other atomic subconfigurations for H in water. In this sense, chemical patterns are simply taxonomic units of classification of molecules and their transformations. Certain chemical subconfigurations (called *functional groups*) usually display a common behavior and are only partially influenced by their structural environment.

The type of ammonia $\begin{array}{c} \text{A—N—B} \\ | \\ \text{C} \end{array}$ comprises amines:



Theory of types gave a strong impetus to chemical theory and already by 1865 the modern concept of chemical connector, in PT terms, was ready to hatch.

Up to present, the basic organic chemistry has been taught to students by types of structure: alcohols, amines, sugars, proteins, etc. The starting chapters are typically entitled as:

Alkanes and Cycloalkanes

Alkenes

Alkynes

Alcohols, Diols, and Ethers

etc., i.e., by patterns of chemical structure, without too much overlapping .

Looking at a big and complex chemical formula, a novice in chemistry is immediately lost, while a more experienced chemist perceives them in terms of known types of subconfigurations. Later, some connector graphs were added to the intuitively defined types, such as the alternating single and double bonds



as well as more complicated ones.

For example, trying to understand formulas in Figure 2.1, a chemist first suspects the pattern of steroids in the connector and then looks at the neighborhoods of atoms.

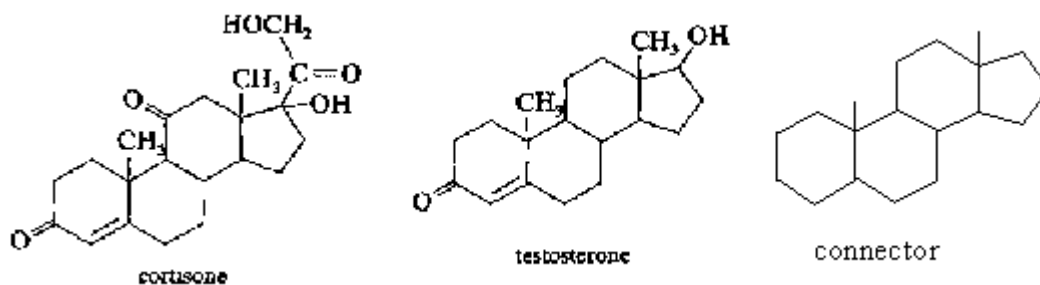


Figure 2.1 Steroids and their connector

Similarly, the connector of porphin defines a pattern to which such important substances as heme and chlorophyll belong, Figure 2.2.

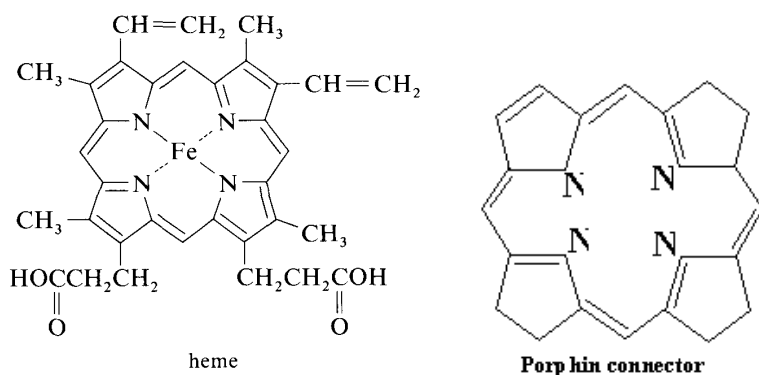


Figure 2.2 Heme and its porphin connector

The chemist perceives an unfamiliar structure in terms of standard superatomic blocks and their connectors. Similarly, the formula of an unknown substance is reconstructed block by block, according to their patterns of behavior and topology. Two blocks are, possibly, neighbors if they belong to a larger block and can be found in the products of its decomposition.

Most practically important molecules belong to several patterns at the same time. Taking to account the interaction between different groups within the same molecule, the concept of pattern in chemistry, clearly visible from a distance, is significantly blurred at a close range. No doubt, however, that a student of chemistry learns to perceive the immense complexity of the molecular world in terms of patterns that look like mathematical formulas where symbols stand for types of structure and transformation. Not accidentally, various shortcuts for large blocs are popular. Thus, R in R—O—H can stand for 61 atoms ($C_{20}H_{41}$) with a very intricate connector.

In the chemical formula of aspirin, Figure 2.3, we find at least three stable subconfigurations from countless other structures: *ortho*-substituted benzene nucleus (*ortho* means side-by-side), carboxyl, and acetoxy-group. Aspirin, therefore, displays at least four patterns:

1. Aromatic compounds, i.e., derivatives of benzene;
2. carboxylic acids;
3. esters;
4. *ortho*-substituted aromatic compounds, i.e., derivatives of benzene with two substituents side by side.

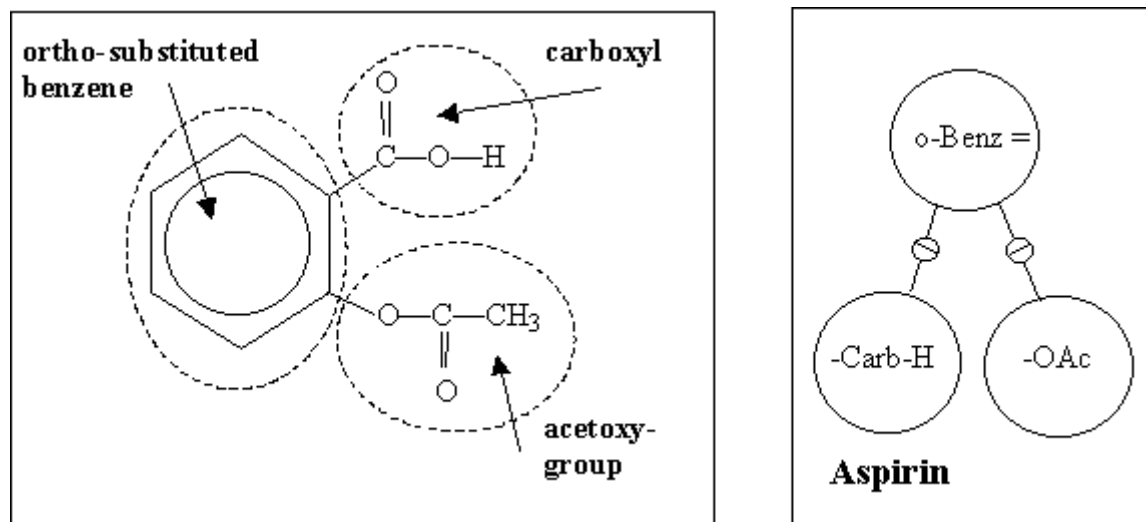


Figure 2.3 Overlapping patterns of aspirin

Any molecular structure can be converted, by standardized international rules, into a string of letters from which the structure can be drawn. Thus, aspirin is 2-(acetyloxy)-benzoic acid, which would look differently in Russian, but have the same meaning. This correspondence resembles, in inverse order, the relation between the text of *Hamlet* and its stage production.

Information contained in a chemical formula can be coded by a matrix of bonding, as the example of formaldehyde in Figure 2.4 shows. Aspirin, $C_9H_8O_4$, requires a 21x21 matrix. Matrices for all large molecules are sparse.

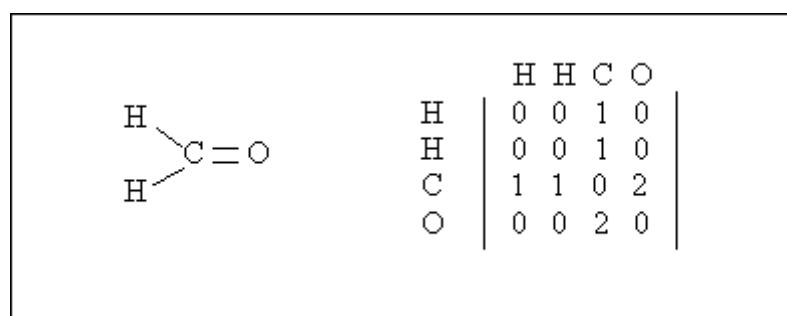


Figure 2.4 Two representations of the structure of formaldehyde

In dynamic representations of configurations, the connectivity matrix can contain probabilities or affinities instead of just Boolean incidence. Moreover, a multidimensional array can comprise all essential aspects of the configuration, including its history, if the configuration is a scale of sets. Thus, the diagonal can store the data for generators and other elements can specify types of bonds: single, double, etc. This method is actually used in computer coding of chemicals.

Chemistry as a testing ground for pattern ideas is interesting also from another angle: perception and understanding of images.

The chemist deals with very complex and large chemical formulas that must be understood. The process of understanding of a chemical formula consists of compiling (partly, subconsciously) a list of all its patterns, as in Figure 2.3. The verbal description and writing the exact chemical name of the substance is the final proof of understanding because **it can be**

shared with another chemist, in accordance with the old saying that the best way to understand something is to explain it to somebody else.

Similarly, the understanding of a picture consists of listing the object in the picture in such a way that it can be shared with another person who cannot see the picture itself. For example: “I see two birch trees on a grassy foreground against the background of a conifer forest.” This renders not the picture but its pattern.

Human understanding, in a way, is a social phenomenon. As soon as the components of an image and their spatial relation are identified in such a form that can be shared, the image, whether a picture or a chemical formula, is understood. Unlike the natural objects that must be subjected to pattern analysis before they can be processed further, for example, in computer vision and recognition, chemical formulas are “turnkey ready” because they are already naked patterns.

3. Regularity and probability in chemistry

Chemistry is a very liberal science in the sense that it has few, if any, strict rules without exceptions. It constantly discovers something that was unthinkable before and is always on the prowl for monsters and chimeras.

To give an example, it had been an axiom that noble gases were unable to form compounds, until in the 1960's the axiom was shattered. This puts a teacher of chemistry on a shaky ground because whatever the students say may be true.

When the authors of this book were undergraduates we were taught that the noble gases did not form chemical compounds. Then several noble gas compounds were discovered in the *early 1960s* [11].

This is why chemistry does not have much to say about regularity. It is part of the chemical credo, rarely expressed publicly, that anything we can imagine is possible. The hidden foundation of this belief is, probably, the isomorphism of thoughts and things in chemistry.

Chemical chimeras can be inspired by some very distant reality. For example, the chemical structures in Figure 3.1—two interlocked rings and a ring on a dumbbell—were synthesized just because of the challenge of the shape. They are, so to say, materialized ideas. By doing that, a chemist becomes an architect.

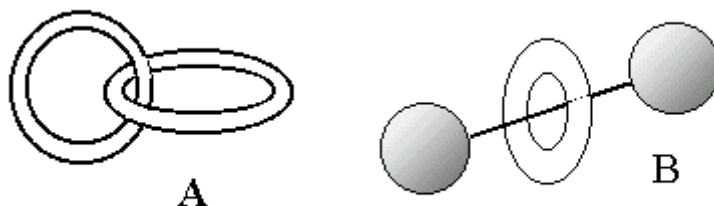


Figure 3.1 Topology of catenanes (A) and rotaxanes (B)

If atoms can combine and form various configurations in our imagination, they most probably can do it in a flask. This kind of philosophical idealism would not survive for long if it were not confirmed by experiment.

“Yes, everything thinkable is possible in fact, but how stable is it?” The chemist asks this kind of question in the situation where the mathematician would ask, “Yes, but how probable is it?” Here lies an apparent difference between PT and chemistry. Where the mathematician thinks in terms of **probability**, the chemist (and, probably, architect) thinks in terms of **stability**. There must be some serious reasons for that, and the main reason is that the configuration space in chemistry is a scale of sets, while a mathematician would probably prefer to deal with individual sets, however fuzzy. It does not mean that the chemist has an aversion to probabilities, but they are expressed as concentrations, i.e., probabilities to find a molecule of certain kind in a unit volume. The law of large numbers works over the entire “real world” chemistry, with the exception of special cases when a single molecule is the object of investigation, as in protein folding.

An important set of rules of regularity comes from quantum chemistry. Quantum-chemical regularity means preserving a certain arrangement of the external (valent) electrons

between atoms. A single line portrays the covalent chemical bond, typical for complex organic molecules. A double or triple line between two atoms (example: $\text{H}-\text{C}\equiv\text{C}-\text{H}$) does not mean two or three identical bonds: the second and third bonds are very much different from the first, and the chemist always keeps that in mind.

Without going into quantum-theoretical specifics, **chemical stability** requires the configuration to have certain regular neighborhoods of atoms. The regular neighborhoods have a certain number of outbonds at the central atom, each of them portrayed by a single bond corresponding to a pair of shared valent electrons. The sum of valencies is eight (octet rule), **for some of the most wide spread atoms**, two for hydrogen, and usually up to twelve for other atoms. It seems like a lack of regularity, but each particular case is explainable by quantum chemistry.

Figure 3.2 illustrates the use of octet rule.

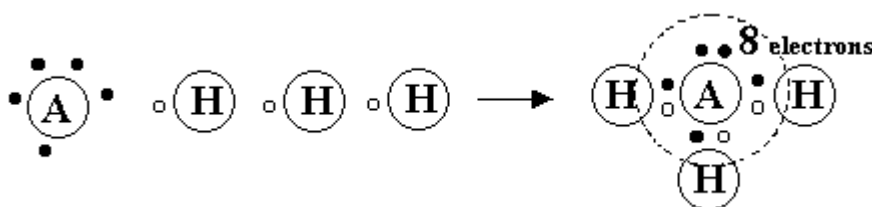


Figure 3.2 An illustration of octet rule

Atom **A** forms a stable compound AH_3 because the neighborhoods of **H** (hydrogen) have regular pairs of shared electrons, and the neighborhood of **A** has the regular eight shared electrons. The different fill of the little circles symbolizes different contributors to the shared pair. The structure is regular and, therefore, expected to be stable, which is always better to check experimentally.

However, even the octet rule is ridden with exceptions. Thus, there are simple molecules where the number of electrons at an atom is seven, as it is at atom **A** in Figure 3.2, where **B** means just another atom, not boron. Nitrogen dioxide, a brownish gas present in the engine exhaust, belongs to this type. The transition between the two forms, monomer and dimer, the latter being quite regular, happens to fall in the interval of temperatures commensurate with

human existence. At the room temperature, the monomer prevails, while at the temperature of melting ice, the dimer dominates, so that the brown color of the monomer disappears. Regularity in chemistry is relative: it is more or less defined for a certain temperature interval.

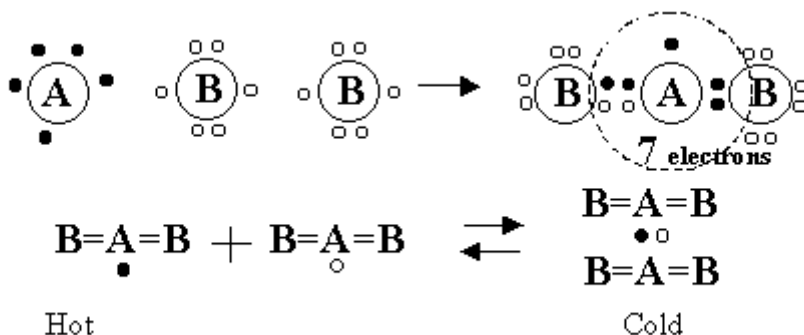


Figure 3.3 Example of a formally irregular but stable structure ($\text{B}=\text{A}=\text{B}$)

For most other chemical bonds, the interval of reversible dissociation and association is much higher, somewhere near the red heat. At any temperature, the two forms are in equilibrium:



Or, in a more typical for chemistry notation,



The position of the equilibrium between these two forms can be exactly calculated because equation (3.2) describes a canonical Gibbs ensemble with complete list of entries, leaving nothing to imagination. In chemical notation, concentration, i.e., **the probability to find** a molecule of a certain type in a volume of the mixture, is symbolized by square brackets and defined by:

$$\frac{[A_2B_4]^2}{[AB_2]} = K \quad ; \quad [A_2B_4] + [AB_2] = \text{const} \quad (3.3)$$

Since the total concentration of molecular species, $[A_2B_4] + [AB_2]$ is known, the concentrations of each species can be calculated.

Naturally the temperature dependence of equilibrium constant K is expressed by

$$RT \ln K = G_{A_2B_4} - G_{AB_2}, \quad (3.4)$$

where T is temperature, R is constant, and G stands for (no surprise!) Gibbs energy, which in chemistry is misleadingly called *free energy*, the term that will be avoided here. We shall return to it later.

Equation (3.1) is not the only possible transformation. For example, we can imagine a decomposition of two **BAB** into perfectly stable two **BB** and one **AA**. And in fact, this is what happens in the catalytic converter of an automobile where the poisonous nitrogen oxide NO_2 is decomposed into harmless nitrogen N_2 and oxygen O_2 . Moreover, the position of chemical equilibrium favors this decomposition! However, it practically never happens if the oxides are left at normal conditions.

If unexplained, the chemical liberalism could take a good bite off our faith in chemistry. Of course, a chemist can eliminate the spontaneous decomposition simply because it has never been observed at normal temperatures (it will definitely happen at high temperatures). But there must be some scientific reason for that if chemistry should not be taken for a kind of soot-saying.

Certain imaginary things happen in fact, since the times of Jules Verne, but others are impossible or need sophisticated tricks to make them real. It seems important to find the constraints of realism to be applied to such areas of thought as mathematical systems, statistical mechanics, and Gibbs ensembles, too beautiful for the challenges of real life.

The reasons for the irrational stability of NO_2 and the persuasive power of catalytic converters will be considered in Part 8.

Theoretically, any combination of atoms is possible, but most of them have such a high energy that they could not exist at normal conditions. The idea of regularity in chemistry, therefore, is tied to conditions. What is regular at one set of conditions becomes irregular at another. Irregularity appears only if we define regularity.

Thus, if we trust the Bible or the Koran to define a set of regular ideas, any other idea becomes irregular.

Chemical regularity, therefore, forms a continuum. Nevertheless, there is a common understanding of what is practically regular. **Regular is what is stable.** Regular molecules are, approximately, those that can be kept in a jar, at least overnight. This probably can be said also about thoughts: a regular idea is the one that can survive in the mind, say, five minutes, all the more, overnight. Probably, scores of vague and irregular ideas fly through our mind every minute, some of them even beyond verbal expression, and most subconscious. Certainly, what is formulated in words has at least a look of regularity.

The chemists operate with energies instead of probabilities because energy is measurable while probability is not. Energy is linked in a chemist's mind with stability: low energy means stability and high energy means instability. Of course, as with everything in chemistry, the borderlines are diffuse.

The chemists do not use probability as a measure of stability, and for a good reason: the complete list of combinations of atoms has a complexity of the scale of sets. Chemical systems do not have a list of all configurations in the configuration space. There is no set of exhaustive and mutually exclusive alternatives or events. This is why chemists rarely use absolute energies, either, focusing instead on differences.

It looks like the chemists are intuitively Bayesian in their approach. The typical question is: we know for sure that the system is in the state **A**. What is the probability of the state **B** at the next observation, **on the condition that it really happens** and nothing else does? To ask such questions, we need to imagine **B** first. Suppose, there is **A** and derived from it **B**. How probable are both if there is nothing else? On such conditions, we arrive at the classical statistical mechanics that ignores what cannot be imagined.

For a chemist, the question what is going to happen the next moment is rhetoric, especially when dealing with evolving systems. The chemist must know the options beforehand. The “Bayesian” form of question, however, allows the chemist to operate not with absolute energies but with differences, i.e., ratios of probabilities, deliberately idealizing the system.

If regularity in chemistry is closely tied to stability, i.e., to energy, it is no different from the situation in any Gibbs ensemble, but **over time**, not over space. If we consider a disjoint chemical configuration in a single copy, the expected result is also a statistical ensemble over a long observation time, provided the system is isolated. Naturally, if the temperature goes up, the regularity will relax.

Chemical synthesis consists of mixing stable compounds, letting the reaction take its course under certain conditions, and, finally, isolating stable products.

To compare, thinking consists of acquiring reliable data, letting the process in the mind take its course, and, finally, formulating the results. In creative thinking, the timing of the process is hardly predictable, which is an oblique evidence that thinking deals with a single mental configuration.

This implies that a chemical transformation runs through a series of **intermediate irregular configurations** that do not last for too long. Otherwise, the result will always be the Gibbs equilibrium. It should be noted that some reactions come to equilibrium pretty fast, but so do competing undesirable reactions.

Unlike mathematics, chemistry not only refuses to deal with infinity but is also hardly ever interested in chemical reactions that take a long time, except in winemaking. The chemical system is dramatically different from a Gibbs ensemble, which is devoid of the time axis. Chemistry is as much controlled by kinetics as by thermodynamics.

A realistic model of the mind, therefore, must accommodate not only for an expanding configuration space, or, in terms of PT, an expanding envelope, but also for the kinetics that distinguishes between theoretically and practically possible events.

4. Thoughts and molecules

Figure 4.1 looks suggestive, but can thoughts have a “chemistry” in more than metaphorical sense? The formal treatment of *assemblies* in set theory and configurations in PT brings the chemical formulas and ideas into the class of formal constructs. If so, **do thoughts about molecules behave like molecules?** This question invokes the spirit of Gödel: are the Gödel numbers of statements about numbers in fact statements? Coming back to the Bourbaki’s theory of structures, in which a mathematical theory contains rules that assign to assemblies the status of terms, signs, or theorems, while the rules themselves do not belong to the formal mathematics, we find that the above question can be answered positive at least as a hypothesis. To add more weight to the answer, we first need to know how the molecules really behave.

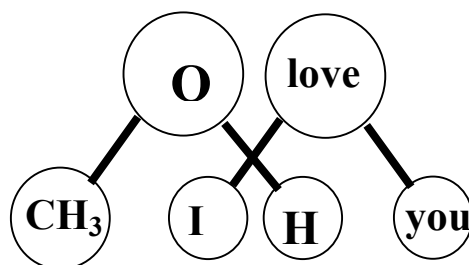


Figure 4.1. A thought and a molecule

Although texts look like polymers of words, there is a notable difference between texts and molecules. The number of atoms is limited by the Periodic Table but the variety of ways they are connected is enormous. The number of linguistic terminal generators, i.e., words, is extremely large, but the variety of their connectors is practically exhausted by a grammar that is much thinner than a telephone book of a small city.

To name its countless objects of study, chemistry uses its own language with a very special relation between the sign and the signified. Regarded as configurations, **the sign is isomorphic to the signified**. In the terminology of linguistics, it is a pictograph, i.e., the most primitive method to code objects by their pictures and to paint a beer mug as the sign for a tavern.

All ancient symbols for small numbers were pictographs: the symbol contained as many elements as the number it symbolized, and it is still true about small numbers in Arabic and Chinese, and, of course, Roman numerals: I, II, III, V, and X. The three first initial Chinese numerals are the same as the Roman ones, only horizontal.

In most languages, a distinction exists between letters and words. The words are combinations of letters, but not separate letters. Chinese characters, used also in the Japanese language, in some aspects, level out the field for letters and words. Various characters, when combined, acquire a new meaning and become a new character, see Figure 4.2. If so, where does this end? Characteristically, in the Chinese and Japanese languages the space between the words does not exist (there are some means of quasi-spacing in the Japanese language). There is no formal difference between characters and words.

偉	Person 人 in contrast 韋 = great	兄	Person 儿 who does talking 口 = elder brother
恍	Heart 心 seeing light 光 = sudden insight	囍	Double happiness 喜 = marital bliss

Figure 4.2 Examples of compound Chinese characters. Components *great*, *seeing* *light*, and *happiness* are themselves compound (source: <http://zhongwen.com/>).

The borderline between molecules and thoughts is blurred in the practical work of a chemist who manipulates atoms and molecules on paper, in mind, or with a computer. In the mind of a chemist, ideas about molecules behave like the molecules in the test tube.

When Hamlet contemplates his actions in sequences of about 30 symbols of English alphabet and syntax, there is no direct conformity between the text and the action, and not much even between the text and the speech. Symbol *S* for entropy in physics looks more like a lithe snake than a state of flaccid disarray. The Gödel number is a far cry of a statement it enumerates.

The situation is different in chemistry where the chemical formula is still a clear pictograph. If it is converted, according to some rules, into a line of text from which the original structure can be reconstructed, it is no more a pictograph. The chemists do not think in the chemical names of substances, unless for a quick communication. They discuss pictographs of molecules. Thus, the idea of water in the head of a chemist, not a layman, is isomorphic to the actual molecule of water. Thinking about water, a chemist imagines its three constituting atoms, bonds between them, and sometimes even the angular shape of the molecule ($\wedge$ or $<$). The chemist is used to think in images of molecules and their transformations, letting them play according to the rules of the chemical game. To compare, a musician may think about music and remember it in finger and hand movements, in addition to sounds.

The chemist deals with ideas of atoms **as if they were** labels pasted on real atoms. In imagination, helped with a sheet of paper or a computer simulation, the chemist lets the atoms and groups dance, bounce, and recombine. The imaginary balls and connecting sticks collide and adjust to each other in the mind of the chemist before the stage of the actual experiment, as well as *post factum*. Sometimes the chemist does it without any guiding idea, but more often, draws from known patterns. Then, after testing the idea in an experiment, the virtual play is resumed, and so on, until a satisfactory result is achieved.

Similar strategies appear to dominate other areas of creativity: writing poetry, doing science, and inventing. Thus, a poet starts with some word, line, or just an idea and grows this seed into a polymer of words, marking up its stressed areas, awkward interference of words, and mutual repelling of lines, changing the sequence until the stress is minimized (or enforced), and doing that in imagination or on paper.

The great Russian poet Anna Akhmatova: “If only you knew from what dirt the poems shamelessly grow.”

Search and fitting for the right rhyme could be as painstaking as shopping by a movie star. The entire creative process, whether in science or, at least, in *pre-postmodern* humanities, falls into the same category of processes as protein folding, during which a line of a polymer through twisting, bending, and writhing, takes the most stress-free shape. The poet, however, invents his or her own thermodynamics.

Moreover, a large stretch of history can belong to this kind of processes, too. For example, the history of France, since the French Revolution up to our days, manifests a remarkable series of twists, turns, and contortions, through which the nation has been “stochastically relaxing” the contrast between the personal authority and the will of the people, see Part 5, *Stability in LMS*, Figures 5.3 and 5.4.

In the pattern model of the mind along Ulf Grenander [1], generators of the mind combine and recombine according to their affinity, which is a function of the previous state, random component, and stable constraints of the system, such as partitions of the generator space. Designing an artificial mind, one can take a different direction from this point, but the pattern-theoretical platform, covering a whole range of structures in the sense of Bourbaki with imposed constraints, will remain the same.

Chemical experience, in a way, is materialized PT.

5. Stability in LMS

It may seem at this point that we have departed from any artificial or natural intelligence, but in fact this brings us to the historical beginnings of AI.

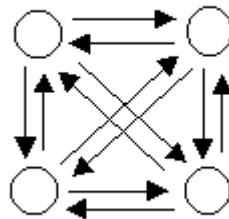


Fig. 5.1 Interactions in the homeostat

Concerning stability, it is appropriate to pay tribute to one of the almost forgotten ideas from the dawn of AI. In 1940, the homeostat of W. Ross Ashby (1903-1972) joined the class of systems consisting of particles interacting under constraints.

Ashby's *Design for a Brain* [12] and *An Introduction to Cybernetics* [13] are a fascinating reading. Ashby seems today, when the general ideas are buried under the sediment of narrow and technical papers, well ahead of his time because his model was, in essence, a

constrained by structure “condensed matter,” close to that of Ising, where topological neighbors influence each other. Figure 5.1 can be seen as an illustration to Ising model. Not only that, but the entire conceptual direction of Ashby presents, on the surface, an alternative to the celebrated Turing’s criterion of intelligence. Ashby’s refrain is **adaptation**. The criterion of intelligence, therefore, is adaptation to the intelligent environment.

Whether it is accidental that the adaptive AI was born in the native land of Darwin and not where Darwin has always been under siege—this is a good topic for a Turing test. An intelligent robot would start talking about the weather.

Extrapolating Ashby’s reasoning, since the environment, populated by humans and animals, from a pack of wolves to a scientific symposium, itself can possess intelligence at various degrees, the intelligence under consideration is measured, like physical temperature, as the intelligence of the environment with which the individual can stay in adaptive equilibrium at least for a day. According to the Turing test, the agent is either recognized as intelligent or not, while the Ashby test (not explicitly expressed by him) could give a measure of intelligence. We use this measure in everyday life. If we can match a person in a conversation, we have at least the same intelligence. The adaptive criterion echoes the Murphy’s law: everybody reaches his or her level of incompetence. As energy in chemistry, the IQ tests are nothing but the measure of the difference in intelligence of the test author and the object of testing.

Of course, an objection could follow that a buffalo has better chances of survival amidst a scientific symposium than facing a pack of wolves. The counterarguments are suggested as an exercise.

While the constraints in a spin glass are topological, the constraints in Ashby’s primitive system of four interacting “particles” are coming from the physical nature of the hardware, namely, from the mechanical inertia of its parts. Being disturbed, the homeostat, after a series of apparently random movements, comes to equilibrium. This system can be roughly compared

with four men (as the least reasonable gender) packed into a telephone booth: when one tries to turn, he disturbs the other three, until they all find the least uncomfortable new position. This kind of system has the topology of full graph, Figure 5.1, the same as for ideal gas where any particle can collide with any other. The connector, however, can be any. Ashby insisted that a large number of particles were needed for intelligence.

What is essential for us is the very type of behavior of Ashby's adaptive system. The homeostat reacts to a disturbance by entering a short **transitional** mode of intense movement and subsequent coming to a new equilibrium.

From the chemical point of view (which may be disputed by some chemists), reacting molecules in chemical environment behave as a homeostat. The action of a reagent knocks the molecule out of balance. A short-living transition state of the running reaction emerges that leads to a new equilibrium.

The mind, notwithstanding the inner mechanisms, behaves in the same way: a disturbance, whether external one or an inner fluctuation ("it struck me," "it just occurred to me") triggers a state of intense work and, therefore, an increased energy consumption until a new state of equilibrium, however temporary, is reached.

Evolution of society consists of periods of balance and stability interrupted by wars, revolutions, and drastic reforms. During the periods of unrest, the society is seeking ways to diminish the social stress, and if it is not achieved, the unrest can take a catastrophic form. A history of a nation consists of periods of relative calm interspaced with times of turbulence. The most spectacular example of the search for stability is history of France, Figures 5.3 and 5.4.

In social psychology, various *balance theories* emphasize the importance of an internal cognitive balance. If two opposite systems of belief violate the balance, the individual tends to adjust them in order to diminish the *cognitive dissonance* (Leon Festinger, [14]). A smoker trying to quit passes back and forth between smoking and non-smoking phases through a painful state of cognitive dissonance.

Ashby's ideas were more refined than it may seem: they included the concept of step function, which was close to the concept of mutation applied to behavior.

What is so unusual and pioneering about Ashby's model is its thermodynamics, which he noted only casually. It is an open system, maintained by an external source of electric current, without which it would come to a hold once and forever. The current brings into motion the cells and feeds the output. The system's behavior, Figure 5.2, consists of alternation of stable and unstable (i.e., probable and improbable) states.

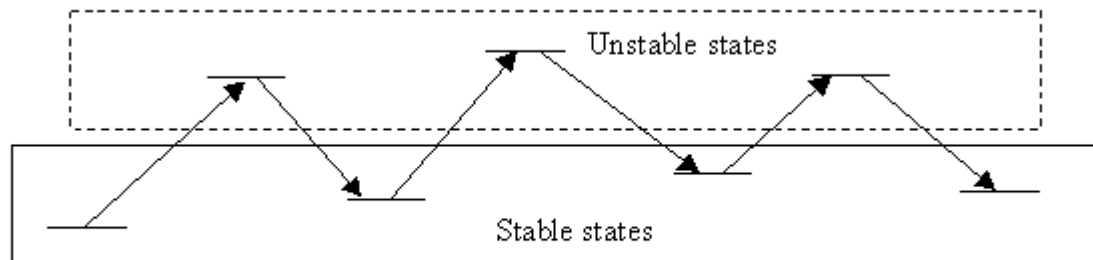


Figure 5.2 Alternation of stable and unstable states in Ashby's homeostat

LMS systems are usually characterized as adaptive. It means that they tend to achieve a state with an optimized parameter, let us call it stability, from which a spontaneous transition to another state is unlikely. If brought into a state far from optimum, they begin a search of a pathway toward stability. A war always ends with peace, but peace is punctuated with wars. The evolution of a stock market belongs to the same type of behavior.

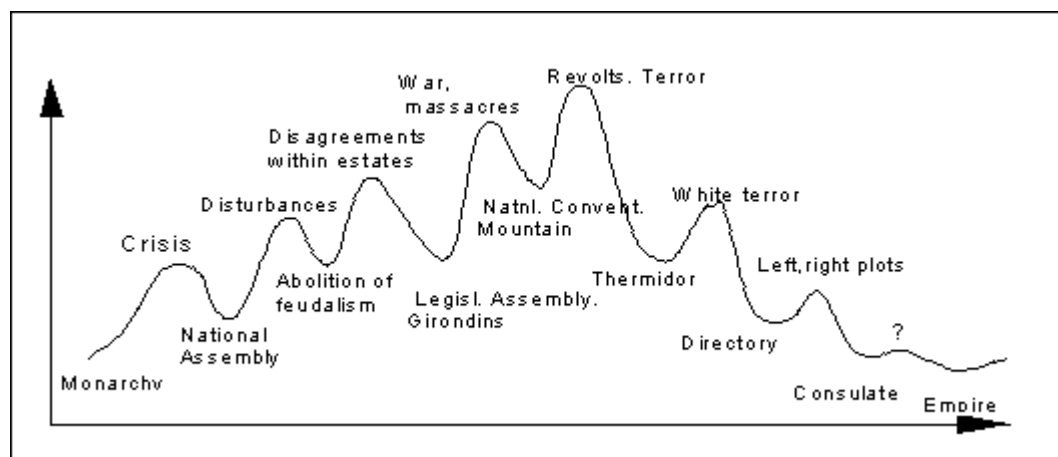


Figure 5.3 The energy profile of the French Revolution. Peaks mark instabilities.

For a physical system, the stable state is that of equilibrium and the measure of stability is energy. The stable state in an open system is not equilibrium but a steady state with a minimal production of entropy.

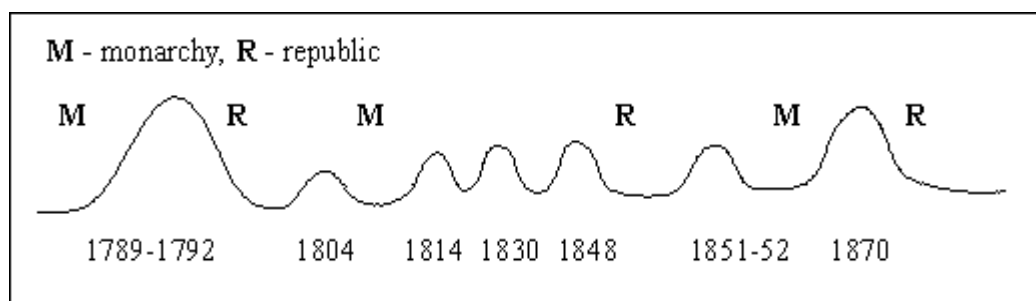


Figure 5.4 The historical roller coaster of France. Peaks mark instabilities.

A problem with open systems is that thermodynamics alone is not able to predict what kind of configuration will correspond to the stable state because thermodynamics has nothing to say about structure.. For example, the turbulent times of the 1960's changed American attitude toward war, but it is impossible to explain in which way by any general concept of homeostasis. Generally, we can expect a roller coaster after September 11, 2001, but of what kind? We need to enter the mind of the smoker as well as the mind of the nation and its enemies to **compare stabilities of different configurations**.

6. Patterns of Transformation.

Taxonomy of real-world chemical transformations is not different from the operations on configurations in *Patterns of Thought*. Chemical configurations are commonly disjoined because they correspond to mixtures of different substances.

The chemist starts with a set of configurations of all participating components and has to decide what is going to happen with it, if anything at all.

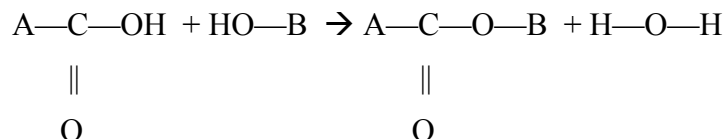
Patterns of chemical transformations usually consist of alternating steps of dissociation and locking of bond couples. In order for the initial and the final products to be regular, some bonds should be broken and other closed because loose bonds are an evidence of irregularity and such structures are unstable unless isolated or highly diluted.

Thus, the chemical reaction of substitution follows the pattern:

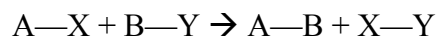


The difference in font symbolizes here the degree of our attention. In the neighborhood of **A**, **B** is changed for **C**. If we switch attention to **D**, **C** is changed for **B**.

Substitution is one of a few general patterns. The lower level includes various specific reactions involving particular functional groups. For example, *esterification*:



This reaction is an example of a more general pattern of *condensation*.



It looks no different than substitution, and in fact, it is not. The particularity of condensation is that $\text{X}-\text{Y}$ is usually a very simple molecule, typically, water. This circumstance is crucial for biochemistry.

Although elementary steps are always simple, they can lead to a catastrophic change of a global connector.

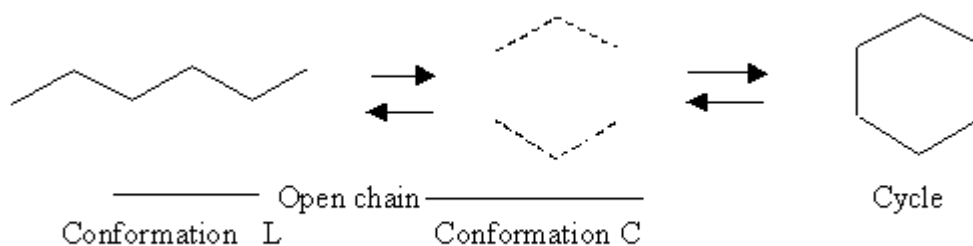


Figure 6.1 Cyclization of linear connector

Much more dramatic examples are known. Thus, the four cycles of steroids (Figure 2.1) can be closed *in vivo* from a linear molecule along a very short pathway.

To jump from a line to a circle, the configuration should take a certain position in the Euclidean background space, shown in the middle by broken lines, Figure 6.1. The ends of the chain must come into a close contact. The open chain and the chain in this pre-locked position are just different conformations, not different configurations.

In most chemical reactions, the events are strictly local in Euclidean background space. The local character of transformation in chemistry is a powerful means to manage complexity.

Such transformations as cycle closure, with the exception of some special cases, require additional energy to overcome the high entropy of distant ends of the forming cycle, which must be somehow compensated by forming additional bond couples.

7. Chemical kinetics and transition state

Chemical kinetics is concerned with the problem of the transformation speed. In pattern terms, it equals asking how fast the probabilities change toward the equilibrium. In the virtual world kinetics can impose limitations on the computation time, for example, the speed of convergence in stochastic relaxation, [2], p. 381.

In the chemical language, the transformation speed means the rate of concentration change.

Thus, for $A \rightarrow B$ (concentrations are in square brackets):

$d[B]/dt = k [A]$, where k is *rate constant*, **specific for each transformation**,

$[A] + [B] = \text{Const.}$

For $A + B \rightarrow C$: $d[C]/dt = k [A] [B]$, $[A] + [B] + [C] = \text{Const}$

For $A + B + C \rightarrow D$: $d[D]/dt = k [A] [B] [C]$, $[A] + [B] + [C] + [D] = \text{Const}$

For $A + 2B \rightarrow C$: $d[C]/dt = k [A] [B]^2$, $[A] + [B] + [C] = \text{Const}$

In other words, the rate of transformation depends on the probability of finding all participating components **in each other's neighborhoods** of Euclidean space. The collision of three and more particles is a rare event and complex transformations go through a sequence of simpler steps.

Note, that the total concentration of particles does not change, unless so intended. This is one of three major limitations of the real world vs. the virtual one:

1. Conservation of matter.
2. Conservation of energy.
3. Euclidean topology.

The meaning of the conservation of matter, in pattern terms, is that in configuration space $\mathbf{C}$, the probabilities $P(G_j^i)$ to find generator G^i in configuration C_j must be strictly normalized:

$$\sum_j P(G_j^i) = 1$$

The chemist does not deal with the unbearable He-complexity of the chemical configuration space, but cuts a small sector out of it, using various heuristics. No wonder, the chemist is often surprised and frustrated when a dark goo and other unanticipated impurities foul up the flask, which happens also with the best of minds.

Euclidean topology of the real world defines how entropy can be estimated. The transition configuration is possible only if all its generators occupy relative positions that make possible formation of new bonds without drastic displacement of atoms.

Considering the process of thinking, a chemist would say that most ideas do not occur to a mind simply because the rate of their formation is too low. This statement would extrapolate chemical experience that asserts that, while everything is possible, only a few transformations are fast enough to be realistically considered. The problem is that transformations go through unstable and evasive transition states. The intimate chemical process is predominantly a

redistribution of electron density, which is something chemistry cannot portray by classical chemical formulas.

The difference between the real dirty chemical world, the mind nested in the real brain of flesh and blood, and the mathematical abstractions should never be lost. Nevertheless, chemistry conforms to pattern theory pretty well. The main reason for that is that PT is as much a theory of regularity as of irregularity.

The tacitly accepted universal chemical principle (see Part 3, *Regularity and probability in chemistry*) that if we have a certain starting molecular configuration, then **anything we can imagine** can happen to it, presumes that generators, i.e., atoms, are neither created nor destroyed, and chemical regularity is preserved. The words “anything we can imagine” used here remind again about the more than metaphoric parallel between molecules and thoughts.

Putting side-by-side real molecules and thoughts may seem a mortal methodological sin. The definition of set given by Georg Cantor, “By a set we mean a grouping into one entity of distinct objects of our intuition or our thought” (quoted from [10], p.322), gives us a hope of absolution.

In a real chemical system, the factor of time can be more important than the position of equilibrium between the configurations involved. In real life, the absolute majority of possible outcomes are never realized for kinetic reasons: because of the conservation of generators, a few fastest transformations quickly **consume** the starting ones and the transformation rate drops. The slower transformations are, therefore, self-inhibiting. Note that the underlying reason is the limited resource of atoms. Different transformations **compete for a limited resource**.

Similarly, for a real mind in a real environment, there is hardly ever enough time for stochastic relaxation. The need to act interrupts the search for “the truth” or the optimum. The *competition for time* limits the relaxation even in the game of chess, not to mention real life because not all alternatives can be optimized and compared.

While the chemical system is always conservative, regarding the generators, it is not clear how this could be realized in the chemistry of thoughts. Intuitively, there could be only one generator “red” or “big” in the mind, but of course, scores of them in a text or speech. It is hard

to accept the idea that thoughts exist in duplicates, unless in different minds. It seems to violate Aristotle's law of identity. Copies are not identical in some aspect: location, storage, whatever. Something must be different, otherwise, two copies are just one.

Another reasonable question is: if most transformations are not realistic, why do they happen at all?

The crucial step to understanding why some chemical reactions happen, while most of them happen only in the mind, was made in 1889 by Svante Arrhenius (1859-1927), who, by the way, made other crucial steps in chemistry (electrolytic dissociation), as well as outside (ideas of panspermia and greenhouse effect).

The aside remarks of the last paragraph may seem a digression if we forget that we compare the thoughts and the molecules.

Svante Arrhenius had a clear idea that even if the transformation is feasible, only a part of all collisions between molecules result in a change, which, in real life, parallels the fact that only a part of all acquaintances result in friendship or marriage. He turned his attention to the rate constant K , which had been a strictly empiric number, and found that

$$K = A \exp(-\Delta G^* / RT) ,$$

where K is the rate constant of the reaction, ΔG^* is *energy of activation*, A is the fraction of "productive", i.e., consummate, collisions, and R is constant.

Universal gas constant R is a form of Boltzman constant k adjusted to the molecular mass: $R = N k$, where N is the number of particles in a mole of any pure substance (Avogadro's number).

Remarkably, ΔG^* is **always** larger than the energies of the initial and final states. It is the **difference** between the energies of the *transition state* and the initial and final states.

The form of this equation (same as for equilibrium) suggests that K reflects nothing but the probability of the initial configuration to reach energy G^* . It follows from statistical mechanics of J. Willard Gibbs (1839-1903), whose name was the source for *Gibbs energy* G that plays a crucial role in the real world because it accounts for its order, as well as chaos:

$$\Delta G = \Delta E - T\Delta S,$$

where S is entropy and E is the chaotic energy of heat (also notated as Q). Here $T\Delta S$ takes to account the degree of order that subtracts from the chaos. Note the deltas: chemists think only in differences.

Gibbs energy assumes that the pressure during the change is constant. There are other measures of the so-called *free energy*, i.e., energy capable of producing work. Gibbs energy is so popular because most chemists work at atmospheric pressure to avoid explosions, unless they use steel vessels.

Following Arrhenius, only the molecules that reach energy G^* (*activation energy*) are capable of transforming into products. A more metaphoric interpretation is that there is a barrier between the initial and final products that is necessary to overcome for the transformation and only a small part of molecules with the asymmetrical Maxwell-Boltzmann distribution have energy sufficient to overcome it.

Turning to real life, to win somebody's heart, you have to be not only insistent (E), but also liked in return (S), if odds (T) are against you.

The change of entropy in chemistry comes from the change in degrees of freedom in 3D space during the transformation. For example, the closure of a large ring from a linear chain is accompanied by a significant loss of entropy, the longer the chain the larger, because the ends have to find each other in ever larger space. As the chemists say, "it is difficult." To continue the

molecule-thought parallel, creativity means connecting distant ideas, because what is close on hand is obvious.

The entire picture of chemical equilibrium, therefore, looks like in Figure 7.1.

Between the **stable** initial state **A** and the **stable** final state **B** (the initial and final states can be reversed) lies an **unstable/improbable/irregular** transition state AB^* . It is the equilibrium between the stable states and the unstable transition state that determines the rate of transformation.

The position of equilibrium between stable states does not depend on the energy of the unstable state because its concentration is negligible.

It is presumed that the equilibrium between AB^* and both **A** and **B** establishes much faster than the equilibrium between **A** and **B**, and only because the probability/concentration of AB^* is low, it becomes the true bottleneck of the transformation.

Rigorous logic may find obvious gaps in this reasoning. We still remain within the equilibrium paradigm and do not introduce any new and radical ideas about the kinetics itself. It is not clear how time can enter the picture.

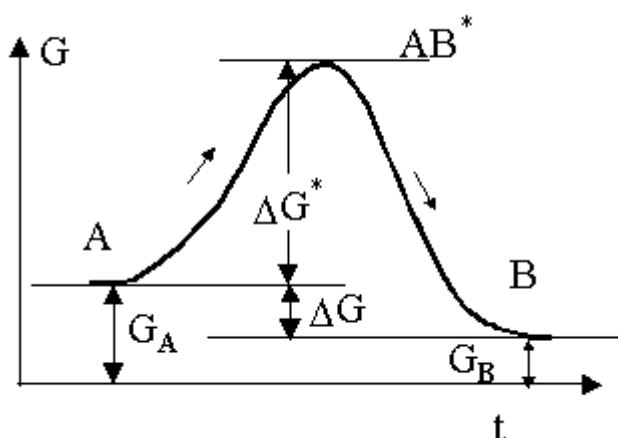


Fig. 7.1 Transformation of A into B

The study of absolute reaction rate and all details of the transition process is a separate area of theoretical chemistry of a strong quantum-mechanical flavor. It is beyond the scope of this paper. It must be noted, however, that the transition state is not a stable substance that could be kept in a jar overnight, but the entire *process* of transformation from **A** to **B**. A possible basis for our kinetic assumptions is that what happens in the transition state usually does not involve any radical displacement of the atomic nuclei and is limited to the redistribution of electron density, which in fact happens, by the human time standards of day and night, practically instantaneously. Anyway, in spite of its logical incompleteness, the concepts of transition state and activation energy serve chemistry very well because chemists, as intuitive Bayesians, operate with differences and not the absolute values. They are not interested in the absolute probability of a structure, which not only can be attained in an infinite time but also depends on what other structures are involved. It will suffice that the structure is stable.

Chemists are trying to figure out the most probable configuration on the condition that the known (sometimes, partially) initial configuration takes place at time t_0 , and the next measurement is taken at time t_n , i.e., for $A \rightarrow B$, they have to calculate $P(B_{t=n}|A_{t=0})$. To remind, the probabilities are expressed as concentrations. A chemist, however, practically never has a complete set of alternatives, which is exactly why chemical experience might present interest for pattern chemistry of the mind. Moreover, the chemist is usually interested in achieving a certain stable state with maximal probability, which is what an average mind carrier pursues, too.

Whether animals think or not is open to questioning, but they certainly pursue goals. What we call *goal* is the imaginary final state separated from the real initial state by a transition state, which is not quite clear in all detail. While pursuing goals, humans and animals alike, or, rather, their minds, work as typical chemists, optimizing the sequence of mental configurations ending with the goal. The usual problem is that another overlooked final state is quite possible. As the story of king Croesus and the oracle of Delphi tells us, final states could be well beyond our imagination even if we have reliable cues.

Along Herodotus, the oracle predicted that Croesus would destroy a great empire. The destroyed empire turned out to be his own.

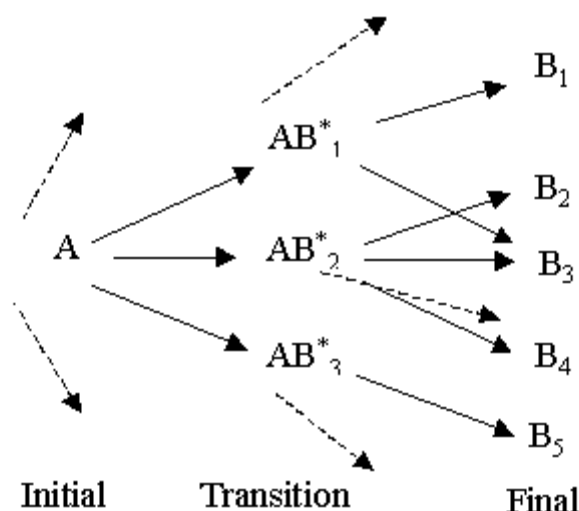


Figure 7.2 An incomplete transformation space. Broken lines symbolize other alternatives, not even imaginable.

The typically chemical situation looks like in Figure 7.2. There are a few possible transition states, each leading to one or a few final states, sometimes, overlapping. The chemical tree of choices is usually incomplete and most of the alternatives are discarded due to prior knowledge (the chemical “system of beliefs”) as well as because of clear cut principles. It is natural to assume that a similar tree of choices, in the form of regular and irregular configurations, should be optimized equally by a wolf or a businessman planning to make a kill, while the deer and the competitor have their own trees.

Bayesian inference has been a subject of numerous arguments and the opinion of a chemist weighs little, but a chemist would suspect that few arguments could arise over a well-defined system. Neither in chemistry, not in intelligence, however, nor, for that matter, anywhere in the world, except in the speeches of political leaders, do we have well-defined systems—a suspicion first expressed by Heraclitus. Thus, an escape from a prison or a catastrophe on the September 11 scale are possible only because neither the prison security nor national security are well-defined systems and some transition barriers happen to be invitingly low when the temperature is high enough.

The idea of transition state comes from the mere observation that nothing happens at once and there must be a reason why events happen at all. If not for the barrier of the transition states, all the molecules on earth would react and fall into equilibrium and all “life’s persistent questions” could be solved in an instant. In fact, nothing is instantaneous.

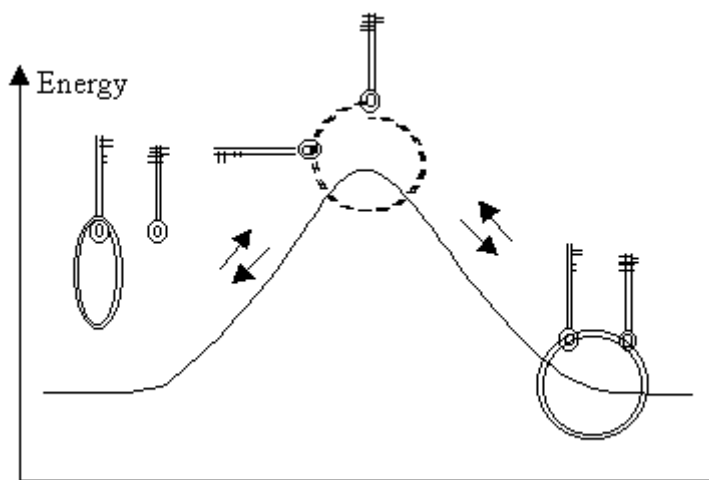


Figure 7.3 Metaphor of bonding

Figure 7.3 metaphorically illustrates the concept of transition state on the process of adding a key to a key ring. In the transition state, the ring is deformed and brought into an unstable shape, which alleviates the attachment of the second key.

Transition state as process is very well known in technology and meteorology. Everyday human activity also consists of stable periods punctuated by short-living transition states, among them, transitions between sleep and alertness. In Asby’s homeostat, all steps of the transition state are observable and recordable.

The following is an illustrations how the same chemical transformation can go through different transition states.

There are two possible mechanisms of recombination $A-B + C-D \rightarrow A-C + B-D$, which the chemists call *substitution*.

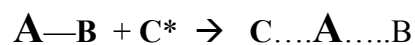
Generator space: A, B, C, D.

Mechanism 1.

Stage 1: Dissociation of a bond



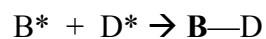
Stage 2: Formation of a triple transition complex and the new bond



Stage 3. Formation of a new bond



Stage 4: Recombination of fragments

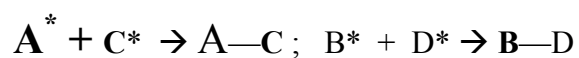


Mechanism 2.

Stage 1. Dissociation of a bond



Stage 2. Recombination of fragments



The arrow $\rightarrow$ means everywhere the reversible transformation $\rightleftharpoons$.

In Ulf Grenander's chemistry of thoughts, a configuration with incomplete bond couples is considered irregular, [1], (2.4), which is consistent with how the chemists see it. Irregular extra bonds, exceeding the regular arity, could also be added to that.

The transition state is always an irregular configuration, usually, with the rule of octet violated. Since transition states cannot be portrayed by common chemical formulas, new symbols were invented for them after their nature had become clear, and of course, by definition, they cannot be stored in a jar. It does not mean that they cannot be studied. Chemistry itself is in a perpetual transition state, few things are static, and we can expect in the future much more detailed knowledge of the intimate mechanisms of chemical transformations. The same can be stated about the science of the mind.

8. Catalysis

The question arises: how could transformations be made simple, selective, and fast if typical reactions in organic chemistry are notoriously slow and tend to run in many directions simultaneously, generating mixtures of products?

The most powerful tool in the chemical time managing is catalysis. Catalysis is a cardinal chemical concept that opens a passage from the classical equilibrium chemistry to the non-equilibrium phenomena of LMS. It prevents chemical chaos inside the living cell. It is easily rationalized in pattern terms. Naturally, some subtleties, meaningful for a chemist but nonessential for the pattern picture, will be sacrificed.

The closest pattern relative of catalysis is signal or message in information theory. While information changes the probability distribution of outcomes toward lower entropy, the catalyst does the same with transition states.

Catalysis has no influence on the position of equilibrium, but, like an earthquake, dramatically warps the kinetic landscape. Similarly to signal and earthquake, it makes a notch on the time axis. It starts at the moment of introducing the catalyst into the system, but in due time, as any information, becomes an old hat. Let us note this property of *novelty*, typical for LMS, because we shall return to it later. The catalytic effect dissipates with time in the same way every news becomes an old hat next day. In the long run, the effect of the disturbance created by the

catalyst is erased by equilibrium. The catalyst itself returns chemically unchanged, as an arrest warrant, after it has been read and produced the desired dramatic effect in a detective story.

In pattern terms, catalysis is based on the interplay between regular (solid lines) and irregular (broken lines) bonds, Figure 8.1. The irregular bonds in question are perfectly regular from the point of view of physics, but not from the pattern-chemical one. They are weak, labile, and often multiple.

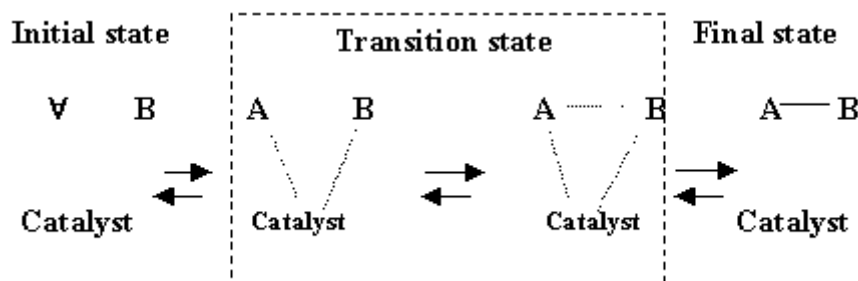


Figure 8.1 Pattern catalysis. Note that **A** is in a wrong initial position for binding

The transformation involves three initially disjoint configurations: **A**, **B**, and **Catalyst**. Configurations **A** and **B** could be subconfigurations of the same configuration, as, for example, the ends of a linear chain.

The entire initial configuration can have high entropy in the Euclidean space where the particles form bonds only in particular spatial orientations and at a close distance. To bring them into the bonding position, with much lower entropy, the energy is borrowed from “irregular” weak chemical bonds shown by broken lines. The transition state undergoes a transformation, coupling the provisional and irregular bond **A---B**, which becomes regular after the catalyst splits off the transformed substrate. This happens sooner or later because of the reversibility of all stages of the process.

The temporary bonds are “irregular” only against a certain definition or standard of regularity in a certain way. As we saw, the intuitive and fuzzy understanding of chemical regularity amounts to the question of stability of a chemical substance. In fact, it is not the walls of the glass jar on the lab shelf that prevent the transformation but the invisible walls of kinetic

barriers. It is appropriate here to compare the kinetic barriers to the barriers of understanding erected by ignorance, prejudice, bias, and habit.

There are different types of chemical catalysis. They all work in three basic steps. The catalyst

- (1) binds to a specific substrate (Gibbs energy decreases),
- (2) forms a new transition state (Gibbs energy increases but stays lower than for the non-catalytic transition state), thereby strongly increasing the speed of the transformation, and
- (3) separates from the changed substrate after the transformation is complete (Gibbs energy decreases and can be either higher or lower than in the initial state).

By catalysis we mean here only the so-called heterogeneous and template catalysis, omitting the homogenous type, which is somewhat subtler.

The distinction between the strong and weak bonds is crucial for catalysis, as well as for all living systems. The weak bonds are very labile, which means that they close and break up in the temperature range where the strong bonds cannot dissociate into highly irregular loose atoms. The weak bonds could be compared with joined magnets or pieces of modeling clay, while the strong bonds are, so to say, locked by bolts and nuts and can be taken apart only with a tool or an explosive. At a very high temperature, of course, all bonds are weak and chemical complexity disintegrates. Properties of various bonds is illustrated in Figure 8.2.

Catalysis simply restructures the energy balance sheet of the system, without changing the bottom line. This is why it has no effect on the position of equilibrium and equally enhances the direct and the reverse transformations. The systems like life, mind, and society exist because the initial intake of free energy and its dissipation into heat and simple metabolites prevent the equilibrium.

If the three initially disjoint configurations—two components of the substrate and the catalyst—lose their independence, it means a significant drop of entropy, which requires energy

to compensate for. If the ΔS contribution to $\Delta G = \Delta Q - T\Delta S$ decreases, ΔG increases, and the reaction slows down. The source of this energy is formation of weak and labile bonds that are outside the area of "regular" strong chemical bonds that are difficult to break (hydrogen bonds, Van der Waals bonds, electrostatic interaction, interaction with the solvent, etc.). The disconnected irregular fragments of regular bonds have high energy and low probability. The fragments of weak irregular bonds, for example, the bonds between molecules of water, are individual and stable regular molecules.

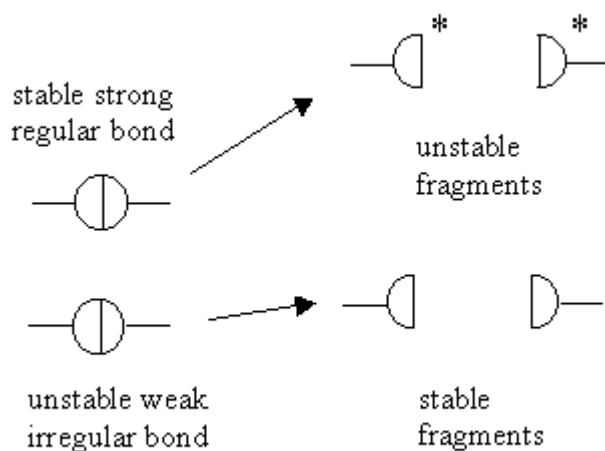


Figure 8.2 Properties of regular and irregular bonds

The most interesting case is when the substrate and the catalyst conform to each other like lock and key. To continue the analogy, some important catalysts work rather like the safe deposit box and two keys to it. Figure 8.3 illustrates this case by the joining of the two keys with a single ring, this time aided by fixing the positions of the keys, which simplifies the operation and eliminates unnecessary fumbling with the objects in the transition state.

It is important to emphasize that the catalyst works in both directions and does not change the position of the equilibrium, which does not depend on the transition state. The remarkable effect of catalysis can be seen only at non-equilibrium conditions, which is exactly what life, mind, technology, and society require for functioning. In the long run, the

thermodynamics overrides kinetics, and the catalytic effect is completely erased. In a non-equilibrium open system, however, nothing is “long-run”.

Transformations of relatively small compounds—small in comparison with polymers—may go in just a few directions because of large differences in ΔG^* between different transition states. If we deal with gigantic polymers, like proteins and nucleic acids, where the configuration space produced by combinatorial explosion, all the polymers have close energies. In such a degenerated system, an ultimate chemical mess would be expected if not for the catalysis. The catalyst brings order into a highly chaotic system and, therefore, works no different of any package of information.

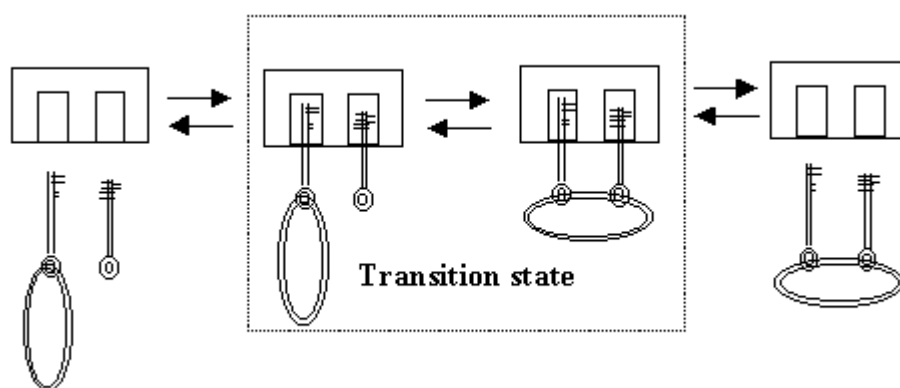


Figure 8.3 A metaphor of catalytic transformation: the joining of two keys by a ring is made easier by the fixed positions of the keys, of course, not by two locks.

A degeneration of configuration space parallels the situation in a computer where any sequence of symbols of the same length requires the same time—and energy—to transfer and process. Classical thermodynamics in both systems does not depend on the content of a configuration, which is always a linear sequence of a limited number of symbols. Unlike the chemical system, the computer is, ideally, completely frozen and nothing happens in it unless on command, while life and society have a significant degree of spontaneity and can extract information from the world

Finally, we shall formulate what catalysis means in pattern terms, without any recurrence to chemistry:

Two generators in the neighborhood of the third are in the neighborhoods of each other.

Or:

Coupling of two generators with the third strongly increases the probability of their coupling.

Or:

The probability/affinity of a bond between two topologically closest generators sharply increases if they are bonded to the same third generator.

The concept of catalysis presents a curious problem related to the lack of the concept of history in physics, where anything that happens for the first time has to be pre-existing. In information theory, the events display between the input and the output and they are of repetitive and reproducible nature. If a pinch of the catalyst is dropped into a flask, however, this may never happen again in the same system with the same result.

W.Ross Ashby noted that circumstance while observing his homeostat. He suggested (in an exaggerated interpretation) that the unique event would simply mean that, for example, the input voltage has been zero for half eternity and then changed to 1 and, maybe, back to zero, where it could remain for the second half of eternity.

An alternative point of view is the fundamental for LMS concept of evolution consisting of a chain of unique events, with the current result explainable only in terms of historical record. The concept of **pattern evolution** means that the generator space and the configuration space, as well as regularity, cannot be formulated axiomatically once and forever. The *historical* (or Heraclitean) systems are characterized by a complete absence of ergodicity: the representative point never passes the same cell twice. Paraphrasing Heraclitus, one cannot step into the same

phase space twice. It expands, contracts, and warps as in the most audacious sci-fi movies. What is remarkable, however, **the same patterns can be traversed repeatedly**. He-systems can be ergodic at the pattern level. There are no principal obstacles for accommodating this view by PT, which could open a case on **patterns of history**, where transition state would take the central place and patterns can be revisited in the pattern space. Nevertheless, the parameter of novelty precludes the ergodicity of classical statistical ensembles.

In the 1950's and 60's, when physicists turned their attention to life, an apparent impossibility to assemble a large molecule from atoms without pre-existing information had been the greatest mystery. From the point of view of physics, origin of life was impossible, although life itself was thermodynamically understandable as a non-equilibrium open system. From the point of view of chemistry, there was no problem at all: in a very large He-complex configuration space, complexity can develop from a very simple combinatorial base set in a long sequence of simple steps.

Looking back, the conundrum was a natural consequence of the inherent reluctance of the pre-computer physics to deal with irreducible complexity, i.e. objects represented by lists that cannot be compressed into formulas. Chemistry, on the contrary, developed as an art of navigating through the irreducible complexity of millions of individual compounds and their transformations. Although chemistry has arrived at a set of general concepts, similar to a well-balanced literary analysis of Shakespeare, the true joy of chemistry can be found in the lab, which is a perennial Wild West.

The basics of the chemical art of navigating in large configuration space include the principle that the change in a large system is sequential and local. Similarly, the marine navigation is based on assumption that the ship does not hop all over the world ocean, from one hemisphere to the other, but moves through a sequence of close positions on a 2D surface.

On the contrary, abstract statistical ensemble of independent particles has no such limitation: under the principle of ergodicity, a sequence of states may be arbitrary, as for the gas-like ensemble of colliding particles. The main property of the virtual world is, probably, that any state of the computer monitor can be followed by any else, even though the sequence of intermediate stages can greatly vary. In the real chemical world, the jumps of the phase trajectory are rare and short. At the same time, jumps in the mind are quite natural.

9. Competition and Selection of Configurations

If cybernetics was the alchemy of the mid-20th century, then Walter, Ashby, Beer and Pask were the Magi. (Andy Pickering, [15]).

Artificial Life (often abbreviated as Alife or A-life) is a small universe existing parallel to the much larger Artificial Intelligence. The origins of both areas were different. Alife arose as an abstract mathematical study of generalized life **after** the molecular biology had taken its modern shape and the molecular mechanisms of life had become transparent. On the contrary, AI, as if anticipating a slow progress of the study of the intimate mechanisms of Natural intelligence (NI), took up the mind as a black box and focused on imitating and amplifying its functions.

While AI is a huge area of research involving many people who pursue practical goals, Alife, though ambitious, remains a kind of an intellectual game. Having come from chemistry, it presents interest as generalization of non-equilibrium and non-linear **chemical** experience.

The full story of AL, with purely chemical roots going back to Svante Arrhenius, is beyond the scope of this paper. Its modern chapter starts with chemist Manfred Eigen (Nobel Laureate in chemistry, 1967). People in AI are aware of his works, mostly from the point of view of game theory, while Alife is well aware of the Ising model. Ilya Prigogine and Manfred Eigen inspired the modern science of complexity, which today is best of all represented by the Santa Fe Institute

(Stuart Kauffman, John Holland, Christopher Langdon, Peter Schuster, and many others). It studies the theoretical aspects of LMS, excluding the US Tax Code, the most complex creation of all.

Ross Ashby captured the state of evolutionary divergence of the emergent AI into computer and life sciences in his *An Introduction to Cybernetics* [13]. In spite of Alan Turing's own biological interests, the Turing Machine gave a great impetus to AI toward computer science rather than life science. Nevertheless, the anthropomorphic Turing test was based on live human intelligence as the reference point and was, in essence, a test for adaptability of AI in the environment of NI. It seems that the advent of computers greatly favored the formal AI in competition with adaptive AI. Today, however, when the exchange of ideas is as common as the exchange of flu viruses, AI, Alife, and science of complexity look like a single continent in the shape of the Americas with Alife as the Panama Isthmus between the science of complexity and AI.

What is abstract life without trees, elephants, and humans who try to destroy and save them all and each other? Alife tries to answer the question "what is life" by modeling the major properties of life at the basic molecular level, but, in the pattern spirit, not being overly obsessed with chemical formulas. Alife accepts the Darwinian paradigm that life is competition of species, such as trees, elephants, and humans, for limited resources in an evolving system. The term **evolving system** means not only that the system is thermodynamically open and far from equilibrium, but, more important for us, is a system of chemical type, i.e., evolving in a complex and rich configuration space. It is a system of competing configurations and patterns that reproduce themselves.

It is a matter of convention whether generators and configurations exist in multiple copies in both structural chemistry and PT. In Alife, as in the material world, generators exist in copies and configurations can multiply. In AI, as in mathematics, two identical ideas are just one idea.

The multiple generators of whatever kind do not contradict the general framework of PT if we assume similarity transformation COPY.

The phenomenon of reproduction has been long known in chemistry as autocatalysis without any biological connotations: the catalyst catalyses its own formation. Figure 9.1 shows how it works in an abstract form.

Configuration **D** (disjoined, as it is common in chemistry), consists of four generators **A** and four generators **B** existing in four copies of each. Two generators are coupled. The multiplicity of free generators simulates the availability of building blocks in the environment.

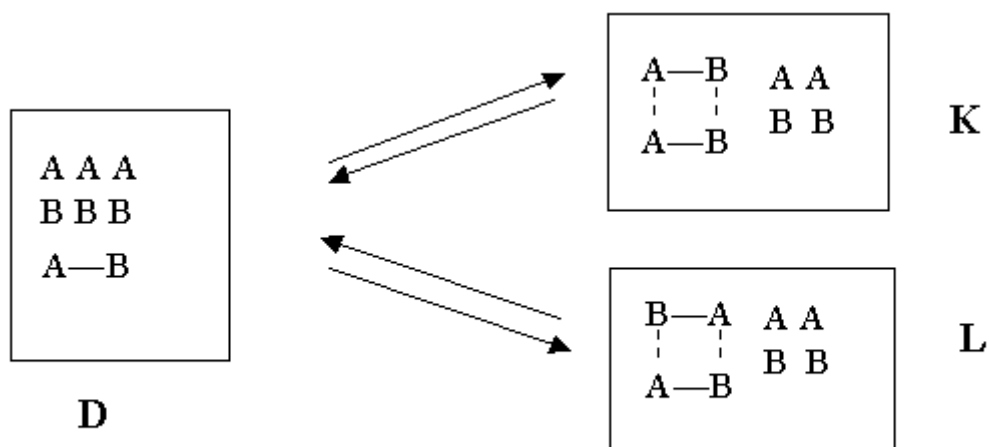


Figure 9.1 Template catalysis in replication

$P(A-A) > P(A-B)$ leads to **K**, $P(A-A) < P(A-B)$ leads to **L**

Suppose, generators can form regular and irregular bonds. There are two cases: identical generators form a stronger (more probable) irregular bond, shown by broken lines, than the different generators:

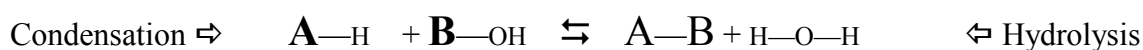
$$P(A-A) > P(A-B) \text{ or } G(A-A) < G(A-B)$$

Then **A—B**, as in Figure 9.1, or **A—A** and **B—B** otherwise, will catalyze their own replication. One dimer works as a template for another.

In the opposite case, when the greatest affinity is between different generators, the replication will be complementary, as in natural life. Note, that the errors are inherent in this

kind of probabilistic reproduction, depending on difference/ratio of energies/probabilities of the two irregular bonds.

The question arises, if free uncoupled generators are irregular, how can they be loose and lonely, as in Figure 9.1? They cannot. In biochemical systems, the **strong** bonding between generators is, at mild temperature, practically always not a coupling but a **recombination**, with the participation of water and its fragments. It is called *condensation*; the reverse transformation is *hydrolysis*.



For biopolymers to be formed, a supply of Gibbs energy is required because the equilibrium involving water is shifted toward hydrolysis. This energy comes from ATP, the universal energy carrier of life. The biochemical details are not essential for us, however. What is essential, biopolymers can form only in a system with consumption of Gibbs energy and its dissipation into heat.

We do not talk about “supply” of thermal energy when considering a system at a certain temperature. We need, however, a supply of Gibbs energy because it is a perishable commodity, turning into heat if not used for work.

As soon as we postulate replication in a chemical system, it becomes a model, although very much incomplete, of life. The pioneering work of Manfred Eigen [16, 17], who investigated the kinetics of this type of systems, gave an impetus to the whole new area

Manfred Eigen was concerned mainly with linear sequences for two reasons: the linear model is the simplest for simulation and it is the closest to natural linear chains such as proteins, DNA, and texts.

Manfred Eigen’s main question was: what can happen in this kind of a system from the point of view of chemical kinetics, provided the configurations act as self-replicators, i.e., each

polymer enhances the formation of its copy from monomers. To ensure replication, a supply of generators (monomers) and Gibbs energy to link them were postulated. The linear polymers multiplied like the hare and lynx in Lotka-Volterra's famous model. The total number and length of generators existing in multiple copies in the basic model were kept constant, although that was not a necessary condition.

The replication is prone to errors and the most probable one is a mutation in a single generator. Hammett distance defines the metrics in the *sequence space*, Figure 9.2. The sequences longer than trimers occupy the vertices of hypercubes with most probable mutations along the edges.

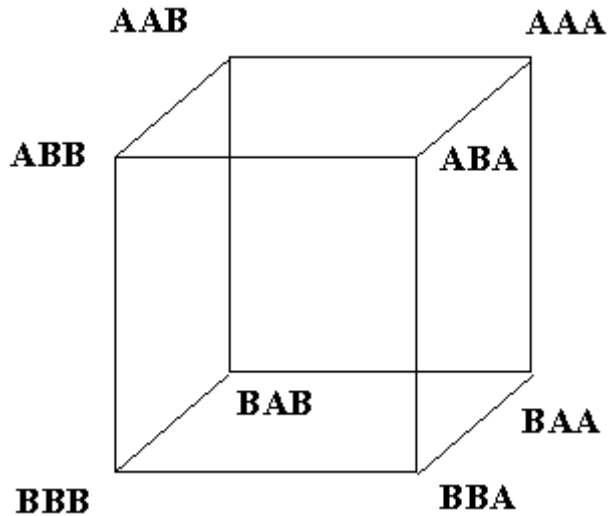


Figure 9.2 The sequence space for trimers

The realism of Eigen's model was not in detail but in the type of kinetics that it employed. It was a starting theme for a multitude of subsequent variations in *Alife*.

In the simplest case, the imaginary system under consideration comprises n species (linear configurations) with $x_1, x_2, \dots, x_n$ individuals in each.

In Eigen's model, the simplest system is described by the following kinetic equation:

$$\frac{dx_i}{dt} = A_i Q_i x_i - D_i x_i + \sum_{j \neq i} w_{ij} x_j \quad (9.1)$$

$$d \sum_i x_i / dt = 0$$

where $A_i x_i > 0$ is the component of self-reproduction (birth), diminished by $Q_i < 0$ as quality parameter, i.e., the measure of errors during reproduction,

$D_i x_i$ stands for spontaneous decomposition (death), and

$\sum_{j \neq i} w_{ij} x_j$ is the production of species x_i through mutations from all the other species.

It is the canonical form of kinetic equation for a system with gain, loss, and interaction. The first term is growth, not necessarily through replication, and the second term is decay. The third term represents influence of topological neighbors. Replication is the only way a population can grow, but the equation is not limited to discrete metrics: x_i can be, for example, probability. The presence of neighbors assumes a topology.

Eigen's simple system possesses Ar-complexity: all generators are listed in advance. The configurations are combinations of symbols of a certain length. Neither the symbols nor the length enter the equations. As Eigen noted, for combinatorial reasons, the number of all possible sequences can easily exceed the number of available monomers. The term evolution can be applied here in its narrow physical sense, as the movement of the representative point over the phase space of a however large but constant volume.

The third term of the equation is similar to the term of the exchange with the neighbors in Ising model. The connector, however, is not a 2D lattice but the sequence space.

The mathematical picture of competition, based on replication with errors, is very general. It seems that various biological and physical models belong to the same general class of processes. The class is described by the differential equations that in the most general case contain the following terms:

1. Birth (or remembering, multiplication, growth, formation, self-perpetuation, success)

2. Death (or forgetting, extinction, decline, dissipation, decomposition, failure)
3. Interaction with topological neighbors in terms of probability of birth and death (in a relaxed version, success and failure).

The phenomena of birth and death demarcate the border between “plain chemistry” and biochemistry, or, to put it differently, between meta-chemistry and LMS.

The possibility of birth and death in an open chemical system needs explanation. It is appropriate to distinguish between two types of bonds, positive and negative, see Figure 9.3.

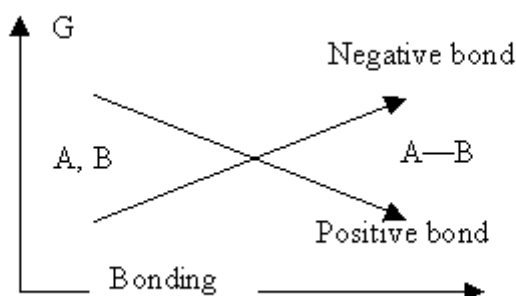


Figure 9.3 Positive and negative bonds

The positive chemical bonds require energy to break them and the negative bonds require energy to form and maintain them. All chemical bonds, whether strong or weak, are positive: the stable bond forms with the release of energy. This is why catalysis is possible: the initial bonding with the substrate is spontaneous.

The quantum-mechanical picture of chemical bond includes the negative and neutral versions as anti-bonding and non-bonding molecular orbitals, along with the regular bonding orbital. They are solutions of Schrödinger equation.

In biochemistry, where the bonds are formed by condensation, with the evolution of water, the equilibrium is thermodynamically shifted toward hydrolysis (breakup) of the

sequence. Therefore, a bond couple between monomeric generators can form only on the condition that energy is delivered selectively to the site of bonding, which is done through ATP (Adenosine Triphosphate) in the presence of an enzyme.

This is not possible in spin models, where the energy may come only from a field. Thus,

the Ising model has the Hamiltonian $H = \sum_{\langle ij \rangle} -J \sigma_i \sigma_j - h \sum_i \sigma_i$ where h is a uniform

applied field. This illustrates the dramatic difference between physical and LMS models.

Thermodynamically, life is a *dissipative structure*, like the eddies in the turbulent flow, Bénard structures in water in a container on a hot plate, tornadoes, and other phenomena existing only due to the supply of energy. The physics of dissipative processes in connection with life was explored in-depth by Ilya Prigogine, the founder of non-equilibrium thermodynamics, and his school [Prigogine is author of numerous books on the subject]. As Eigen formulated, “Systems of matter, in order to be eligible for selective self-organization, have to inherit physical properties which allow for metabolism, i.e., the turnover of energy-rich reactants to energy-deficient products, and for (‘noisy’) self-reproduction. These prerequisites are indispensable.” [16].

The mind, located in the brain, 2% of the body by weight, consumes 20% of energy. We do not know how this energy is used, but it is obvious that only a small part of all daily content of the brain leaves any trace in it, while a part of the earlier stored material disappears. Two hypotheses on thought dynamics can be inferred from this fact.

The first hypothesis of cardinal importance is that the **thoughts**, or whatever configurations in the brain are behind them, **must compete for the energy supply** in order to come to existence, albeit for a short time. Like the polymers in biochemistry, they need Gibbs energy, and, probably, they are polymers of a kind, in the pattern sense.

The second hypothesis is that the conscious thoughts are just the top of the iceberg, like the most active molecules in Maxwell-Boltzmann distribution. They reach the high energy level

of consciousness. Below them are scores of other—subconscious—configurations that fall into the medium part of the distribution.

The remarkable consequence of competition for a limited resource is that it displays in time because of the form of the canonical equations. The goal of the “survival” is to “multiply existence” toward the next moment. This is how time enters the picture.

The complexity of life appears to be a consequence of an extremely large size of biosphere, while the complexities of modern society come from the limited size of the globe. As far as mind is concerned, the interesting question is the relation between the size of the real world and the upper and lower limits of the size of the mind that can adapt to it. Obviously, the size of the world of a squirrel is not only small but also fluctuating within a limited range. The size of the human world, however, is that of an expanding He-system. Probably, it was the use of tools and language that launched the expansion. It can be classified, in Eigen’s terms, as a hypercycle: each segment of the closed cycle catalyzes the next. Without the scale-of-sets mechanism, however, it is difficult to understand why life has been growing more complex throughout history. The population dynamics alone does not explain it.

The mathematical analysis of Eigen’s system showed a complex behavior depending on the ratios of the coefficients in the equations. The selected configuration is a **population**, not a single species, with a probability distribution of configurations around a certain average. The population may either drift through a sequence space or come to a dominating population, or experience a collapse of information content. Populations are characterized by their *fitness*, which is a value similar to energy (but is maximized instead of minimized in spontaneous processes). The populations have certain positions on a fitness landscape, where those with high fitness (high stability) reside on peaks, while the unstable ones take up valleys ([5], p. 199).

It is the concept of a landscape that unites all LMS systems because it introduces a universal function similar to Hamiltonian in an abstract metric, but generally non-Euclidean, space. Within the framework of Alife, it is the sequence space. Ulf Grenander calls its intellectual version *mindscape* ([1], 2.9). As it can be seen from figure 7.2, a chemical system of a sufficient complexity is also a peculiar collection of points on an energy landscape (*chemscape*) consisting of

peaks of the transition states and valleys of stable states. The positions of the points are neither independent nor static.

The concept of fitness landscape is appealing as a metaphor, but highly controversial. Thus, according to the concept, on a smooth landscape, two close sequences may have close fitness, while on a rugged landscape, a step aside may have dramatic consequences. But why? The concept does not provide any causality. Moreover, it does not take to account the kinetics that may drastically disrupt the bliss of classical statistical mechanics. Besides, as Alife realizes, the landscape changes right under the feet of populations. The LMS science of the future can draw realism from chemistry in its generalized form of PT, however complex it may seem.

Next, some general principles of evolving He-systems will be illustrated by computer models.

10. The Competitive Mind

Birds do it, bees do it
Even educated fleas do it
Cole Porter [18]

If molecules, species, things, and humans compete, then thoughts—their shadows in the mind—must do it, too.

Henri Poincaré (1854-1912) seems to be the first to express, around 1901, the concept of thoughts competing in the mind for a limited place in consciousness [19]. His reasoning had the same starting point as, much later, Manfred Eigen's. As Poincaré put it, it would take a whole lifetime to examine all thoughts and facts in human head one after another, although the absolute majority would be absolutely useless for thinking in a certain direction. Poincaré was puzzled by the observation that the irrelevant thoughts were unable to step over “the threshold of consciousness” and ever come to the mind of the thinker.

What is the cause that, among thousands products of our unconscious activity, some are called to pass the threshold while others remain below? Is it a simple chance which confers this privilege? [19]

Antonio Damasio, who works in the area of neurobiology of the mind but has a bird's eye view of the entire area of mind research, used a similar language in 1999.

...I sense that stepping into the light is also a powerful metaphor for consciousness, for the birth of the knowing mind, for the simple and yet momentous coming of the sense of self into the world of the mental, [20], p.3.

Manfred Eigen noted that out of about 10^{100} proteins of moderate length (more than the whole universe can comprise) the absolute majority are quite useless for living organisms and do not exist. Both Poincaré and Eigen pointed to the process of selection, which in the historically cloudless times of Poincaré meant only Darwinian selection. Eigen specifically mentioned Darwin.

We have to derive Darwin's principle from known properties of matter, [16], p.469.

The only difference between the terms *competition* and *selection* appears to be that selection is the result of competition. Formally, however, selection, meaning reducing a set to its subset, can be done without competition. Biology makes distinction between natural and artificial selections. Selection here is understood as natural, i.e., stochastic. In the adaptive systems of AI, based on learning, the creation of information is the result of teaching, while in natural selection the human teacher is nowhere to be found and the set narrows because of the competition for a limited resource.

The central question for us is how to apply the kinetics of selective systems, developed by Eigen, to the mind where configurations do not form multiple copies and there are no populations of chemical or biological type. A tentative answer is that instead of concentrations, typical for chemistry, we have to come back to PT probability. In order to do that, we need a well-defined system with a finite set of possibilities, which seems impossible for a He-system by definition. As we shall see, we will still be able to have populations of a kind: in time, not in space.

The problem, therefore, splits into two sub-problems: competition on He-structures and building up a He-structure that could code the history of the system. The first problem amounts to a change of connector from hypercube to tree or an irregular Bethe-type lattice, as a prelude to scale of sets. A model for a He-configuration space will be considered in Part 11, *SCALE*.

10.1 BIRDS

To illustrate the principles of simulation, we start with an Ising-type square lattice as connector.

The model is called BIRDS because its behavior is reminiscent of a flock of birds that sometimes change the direction of flight in a coordinated way, but with a certain degree of dissent. It does not aim at simulating avian behavior, for which there are plenty of much better models.

The description of the algorithm follows.

The program calculates directions of birds in a flock.

There are 36 birds B_m ($m=1,2,\dots,36$) in a flock.

The topology of the flock is a rectangular 6 x 6 grid.

The birds are numbered:

1	2	3	4	5	6
20	21	22	23	24	7
19	32	33	34	25	8
18	31	36	35	26	9
17	30	29	28	27	10
16	15	14	13	12	11

The order of numbering is chosen to differentiate between inward and outward bias for some experiments. The program compensates for the lower arity on the fringe of the flock.

Most birds have 8 close neighbors. For example, #29 has # 13, 14, 15, 30, 31, 36, 35, and 28 as its neighbors.

Each bird can move in 32 discrete directions α_i ($i=1, 2 \dots 32$).

The probability that bird B_m moves next moment in direction α_i is $^*P_{m,i}$.

The next state of the system is determined by the 36×32 matrix of probabilities $^*P_{m,i}$.

BIRDS calculates the probability distribution *P over all directions for bird B_m as:

$$^*P_{m,i} = P_{m,i} + M_{m,i} F + \sum_k (g_{k,i} P_{k,i}) , \quad k \neq m,$$

where $P_{m,i}$ is probability in the previous distribution, $M_{m,i}$ is memory about previous distribution, $F < 1$ is parameter of forgetting, $g_{k,i}$ is parameter of influence, $k \neq m$, and k marks all neighboring birds.

The new distribution is stored in memory. $M_{m,i} = P_{m,i}$ for all birds and directions, except for the previously selected direction. To make room for experiments, each bird remembers its last selected direction I as $P_{m,I} = \mathbf{C}$, but the neighbors remember it as $P_{k,I} = \mathbf{H}$. It is not reflected in the above equation.

It means that each selected direction stores $\mathbf{C}$ for this direction in the memory of the bird, but the neighbor who witnessed the turn accepts it as $\mathbf{H}$. The higher $\mathbf{C}$, the higher individual conservatism. The higher $\mathbf{H}$, the higher global coherence.

Interpretation: each bird tends to move in the **same** direction, but it also tends to **forget** this direction. It is also **influenced** by its perception of the movement of several close birds in the flock..

An anthropomorphic interpretation is that the bird “thinks” about choosing a direction, taking to account its neighbors, and 32 thoughts compete in its brain. There is only one winner.

Parameter **H** reflects how a bird, that suddenly changes its direction, is perceived by its neighbors: do they take it seriously? **H** is the measure of “seriousness.” **C** is parameter of conservatism, **F** is parameter of flexibility. The **H/C** ratio characterizes how much attention the neighbors pay to each other’s initiatives. Parameter **g** is generic, taking values **gin** and **gout** (see below).

The program has two kinds of output. One is the grid with the numbers of directions, Figure 10.1.1, and quiver diagram, Figure 10.1.2.

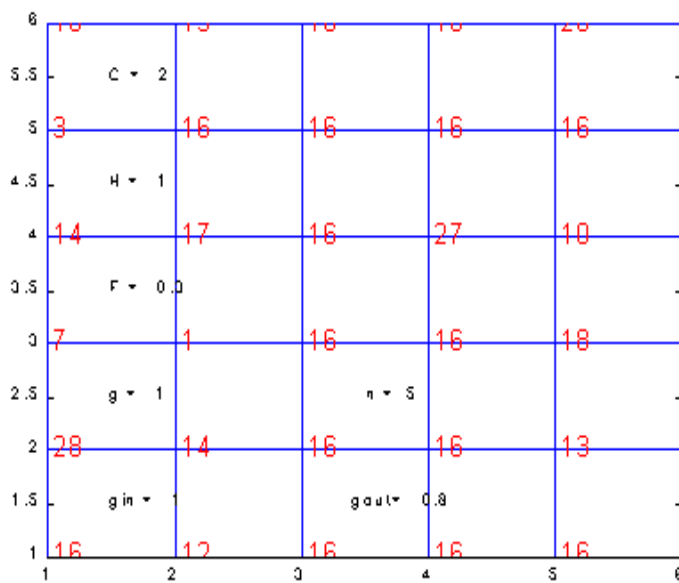


Figure 10.1.1 Example of grid output; directions are red numbers at the nodes

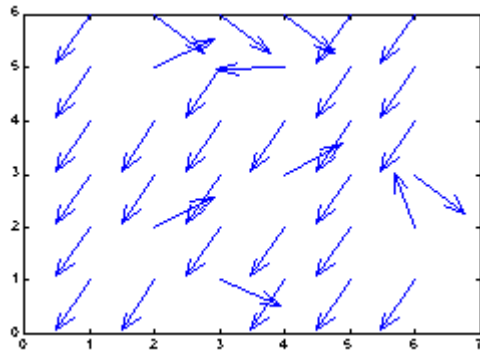


Figure 10.1.2 Example of quiver output

The quiver output is generated by script **qb**. It is the very last line of the program. If it is removed from the code, the grid output will be seen.

Additional parameters:

n: number of program cycles;

d: initial direction, one of 32 around full circle. It is not present in script **bf2**;

gd: influence of the last direction **d** on the probabilities of directions **d+1** and **d-1**, i.e., “circular neighbors” on the dial of directions. Instead of this stiff distribution, normal distribution for directions could be used, but not in this program.

gin: influence by a neighbor with a higher number (inward).

gr: bias toward the center of the flock or outward; **gout=gin*gr**

gout: influence by a neighbor with a lower number (outward).

Script **bf** is used to start the simulation with equal probabilities. It erases the previous information in master matrix FL. It has preset parameters that can be changed by entering new ones. After that, script **bf2** is recommended for changing one or a few parameters, with the arrays intact.

To use BIRDS, copy the workspace BIRDS.mat , copy scripts bf.m , bf2.m, and bq.m.

Start by entering bf. After that, use bf2. For bf2, n=1 to 10 is recommended. In this mode, drastic changes of direction can be observed even after one cycle. However, only after a certain number of cycles (50-100), the system enters the collective mode. In terms of physics, it reaches a steady state far from equilibrium. At C=1, coherence is low, but at C=2 it is clearly seen.

An example of several consecutive outputs is shown in Figure 10.1.3.

In terms of Ising model, BIRDS is a lattice with 32 values of “spin” number. The nodes tend to coordinate their “spins,” preserve the previous position, but lose its memory due to thermal

relaxation. Competition takes place between the values of “spin,” the selection ratio is 32:1. Small changes of direction are preferred. Parameter **gd** relates to the degree of preference (none for **gd**=1).

In terms of collective human behavior, the model approximately corresponds to a group of students in an auditorium choosing among a set of actions and trying to accommodate the actions of neighbors. There are many other similar interpretations in the area of collective behavior.

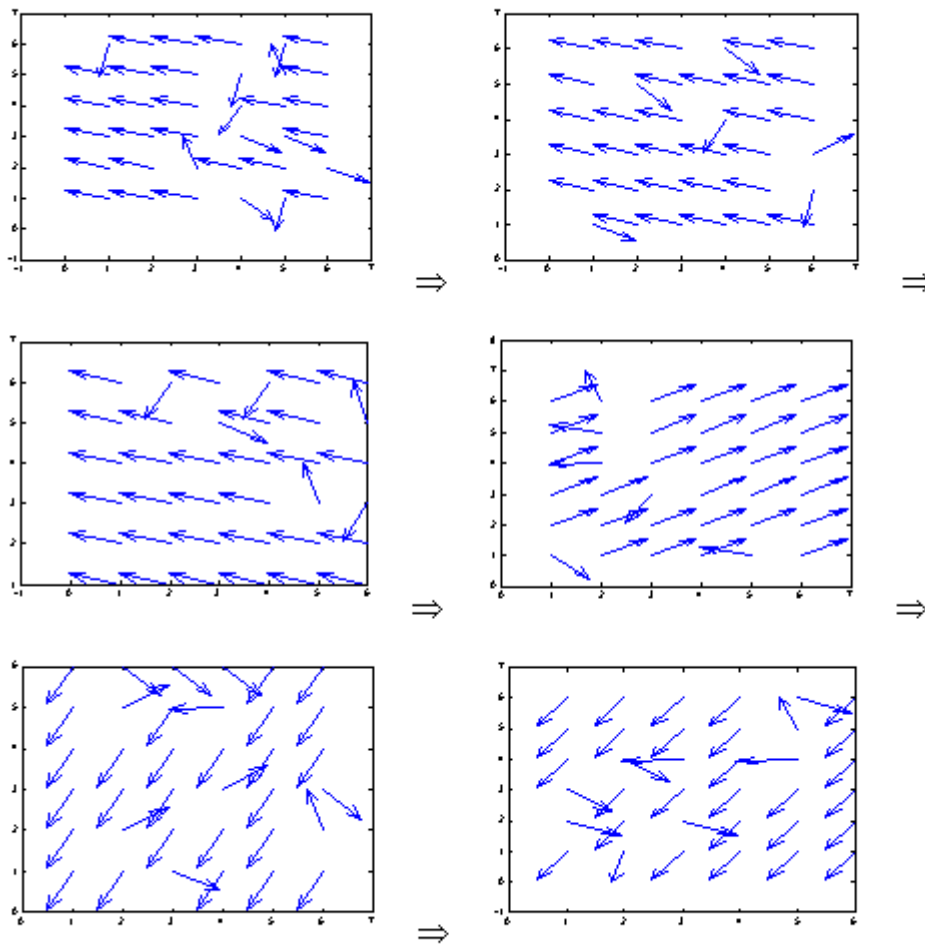


Figure 10.1.3 Examples of output of BIRDS

Although BIRDS imitates some aspects of social behavior, its connector is socially unrealistic. The social topology in the Communication Age is an intriguing topic. The connector is by no means a full graph, as early enthusiasts of Internet expected. Its typical subgraph is, probably, a star with many rays.

The program size does not depend on the size of configuration space. The model consists of two layers of different complexity. One has the local complexity of arrays and the other has the global complexity of the parameters. The devil here is not in the details of the arrays, which are updated by the program, but in global parameters, which require input and can be numerous, generating a combinatorial complexity of their own. Nevertheless, their number never comes even close to the size of the generator space.

10.2 PROTO

Let us try to apply the idea of BIRDS to the competition of mental patterns (“thoughts”) for an unspecified limited resource, which we call, following Poincaré and Damasio, **the spotlight of consciousness**. It is just a name of a model that, as any model, should not be understood too literally unless it looks persuasive to a specialist closely familiar with the real world.

The following scalable system, called PROTO, simulates some aspects of selection on a connector representing an area of knowledge. It is simpler than BIRDS.

PROTO calculates the probability of a generator to win the competition for the next selection. This time, unlike BIRDS, we have only one winner for the entire generator space.

To remind, in a scale of sets, each configuration or pattern is represented by a single generator. This is why the difference in terminology between generators and configurations does not really matter. At the same time, the difference between the up or down direction of bonds, important in [1], is important in PROTO.

The connector here mimics a radial lattice of Bethe type, also known as Cayley tree, Figure 10.2.1.

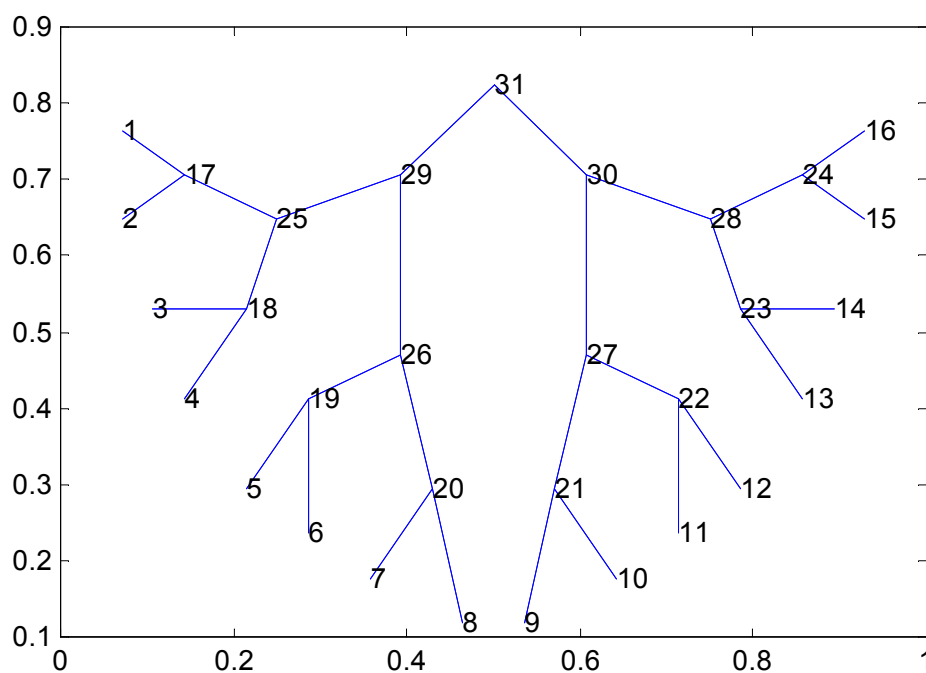


Figure 10.2.1 Connector of PROTO

The topology of the connector graph with 31 nodes can be seen as a subscale of sets built on the base of 16 elements. It can be partially interpreted, for example, as:

1. Cat	4. Tiger	25. Animal
2. Dog	17. Pet	29. Living form
3. Lion	18. Wild feline	31. Material object

The connector can be made much more complicated, for example, nodes 1, 3, 4, and 18 can all be connected to an additional node **feline** (25A), connected also to node 25, Figure 10.2.2. The connector does not need to be regular and the Cayley tree can be somewhat disheveled.

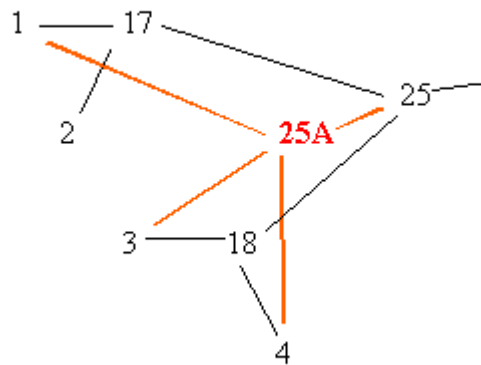


Figure 10.2.2 Node 25A, *feline* is added to the connector in Figure 11.2.1

PROTO calculates probability P_i of selecting generator G_i ($i = 1, 2, \dots, 31$) at time $t+1$. The generators are selected at random, according to their probability distribution.

We attribute the following properties to the generators in PROTO:

1. The longer the generator is in the spotlight of consciousness, the longer it will stay there, by making, so to say, its own copies in time.
2. The longer the generator stays in the spotlight, the shorter time it will stay there because of forgetting.
3. The neighbors in the connector graph positively influence the generator.

The question how a generator can sense the probability of a neighbor will be left here without an answer, but with mentioning the wave function in quantum physics as a very distant metaphor. *To keep up with the Johnsons* is another one.

Calculation starts with the distribution of probabilities at time t . PROTO remembers only the previous probability distribution and is a typical Markov process in an Ar-system. .

The following equation describes the behavior of PROTO:

$$P_i^{t+1} = A P_i^t - F M_i + \sum_{i \neq j} P_i^t g_{ij} \quad (10.2.1)$$

$M_i = P_i^t$, except for the generator selected at time t , for which $P_i^t = C$, but $P_i^{t+1} = 0$.

This is not a necessary modification of the basic Eigen's equation. It is done in order to exclude the earlier selected generator (*acton*) from the next selection and prevent the stagnant repetitive selection. It simulates the phase of rest after the excitation of the neuron and keeps the ball of excitation in the air. Another complication, for the sake of experiment, is that the neighboring generators accept acton's probability as $C \cdot H$, but in acton's own memory, the past probability is written as C , similarly to how it was done in BIRDS. To simplify the picture, $A=1$ everywhere.

On this basis, the probability distribution for the next selection is calculated. The absolute values of parameters do not matter because the distribution is always normalized.

The model uses parameters:

F, forgetting; **C**, memory of an acton right after selection; **H**, factor of perception of acton's probability by neighbors, and **g**, factor of influence, which for the tree connector can be split into **gup** and **gdown**, depending on the direction on the tree.

Parameters **gup** and **gdown** are designed in such a way that the arity of the node is taken to account. The experimenter can play with them, too.

At a certain combination of parameters, the system can freeze around some nodes, slowly drift over its phase space, retaining its compactness, scatter over large areas, or it can jump between distant areas, imitating a spontaneous hypothesis about some new properties of the world. This link between distant nodes is a precondition of creativity.

PROTO spontaneously scans not just generators, but also their bond couples. The phase trajectory of the system, i.e., the sequence of actons, can be obtained as output.

Simply speaking, the more we think about the subject, the more we tend to think about it next moment, but the more we think about it, the more we get tired of it and tend to jump to something else (and this is exactly what various asides in this paper illustrate). These simple principles, as well as the influence of close neighbors, as Manfred Eigen demonstrated, describe “natural” selection of structures built of atom-like objects.

It is important to bear in mind that we do not use here any knowledge about the nature of neural processes in the brain. A neuro-physiologist would say “firing” instead of selection, but we carefully avoid any physiological interpretation. Nevertheless, neurophysiology in an oblique way influences some aspects of the model. The “naturalness” of the model lies in the most general principles of competition and selection in living systems, but not in its details.

The same principles define the Lotka-Volterra systems. The more hares today, the more tomorrow. The more hares today, the less tomorrow because the lynx will multiply. Such “games of life” over many millennia shaped new species, creating new genetic knowledge.

The MATLAB program PROTO requires workspace PROTO.mat, is stored as scripts proto (main), proto1, and proto2, and generates a figure of the tree with red asterisks meaning acts of selection (actons).

The output of the system, depending on the number of iterations n , is a **population** of actons of size n over a segment of time $t=n$. To visualize the population, the positions of the asterisks symbolizing consecutive actons are slightly randomized. The green asterisk indicates the starting node. The starting node can be externally enforced in the beginning or at any moment during an experiment. In principle, two or more actons could be enforced, in a Pavlovian mode.

To activate the program, save workspace (matrices P, T, and GXY) and the scripts. The main program offers a choice of starting from equal probability distribution (proto1) or continuing from the previous workspace, parameters, and probability distribution (proto2). The starting program can prompt for:

n, number of steps (selections),

a, initial acton, from 1 to 31,

C, memory of previous selection as acton; stored in the memory of the acton,

H, factor for probability of the acton, as neighbors see it: $P_a = C * H$.

F, factor of forgetting; if set to a value >1 , it corresponds to Eigen's $A > 1$.

The following parameters are preset, but can be changed:

gup=0.5, parameter of influence upon neighbors (toward the root of the tree), and

w=2, **gdown**=**w*****gup**.

Prompts can be blocked or activated in the PARAMETERS SECTION of the script.

The parameters can be changed by entering at any point between the executions. The initial settings are:

```
H=0.7; F=0.9; C=1; gup=0.5; w=2; a=2; t=0.1
```

Entering **tra** , after the program stops, gives the sequence of actons. Matrix PP (31,2) is the probability distribution, normally not displayed.

To test the program, load the workspace, type **proto** and set the rest of parameters equal to one (which is not quite realistic).

The program includes pause **t** after each selection, in the end of the code. Parameter **t** is set to 0.1 sec.

Large **C** and **F** make the walk conservative and restricted to small areas. High **H** , **gup** , and **gdown** increase ergodicity.

If some parameters should be kept constant in order to minimize input, the necessary modification can be easily entered into the code.

The basic matrix P (32 x 11) in the code has a spare column 10 for modified experiments. It has a spare row 32 with zeros. The connector graph is coded with matrix T (31 x 31). The coordinates of the nodes are stored in matrix GXY. Number 32 is used instead of 0 to signify the absence of a

neighbor, in order to avoid a problem with zero coordinate of a matrix element. Row 32 stores zeros.

A hypothesis silently incorporated in this model draws a parallel between the action of a catalyst in chemistry and the match-making properties of nodes. It states that two generators that are close to a third one are close to each other even if they are not coupled. For example, if in a certain knowledge representation CAT is close to PET, and DOG is close to PET, CAT and DOG are closer to each other than if there was no such triangulation. On the contrary, CAT and GRASS are not in the same neighborhood. Yet, if in our representation MOUSE is in the GRASS and CAT is in the GRASS, we expect a HUNT, i.e., a link between CAT and MOUSE. Regardless of that, MOUSE, CAT, and HUNT form a stable cluster in yet another or the same representation.

The following examples illustrate the behavior of PROTO.

PROTO was run at: $a=2$, $n=50$, $F=0.8$, $H=0.2$, $C=2$, $gup=0.5$, $w=2$ (therefore, $gdown=2*0.5=1$). The results are shown in Figure 10.2.3, where two populations of “thoughts” can be seen.

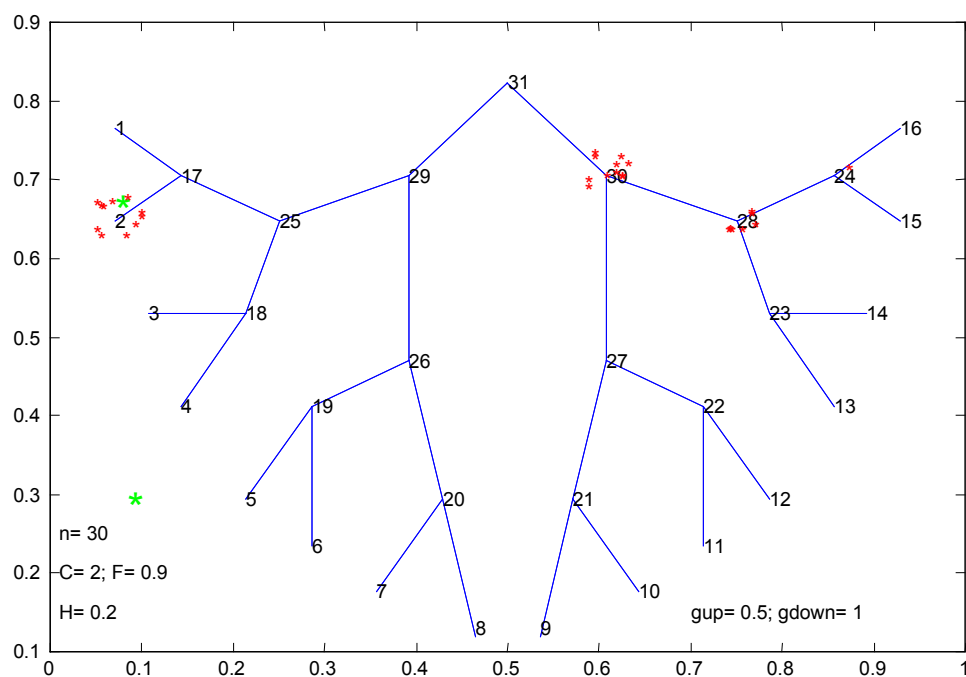


Figure 10.2.3 Two populations of “thoughts” in PROTO , 30 cycles

The trajectory of the system was (after initial acton 2):

tra = 30 → 28 2 30 2 30 28 2 28 2 30 2 30 28 30 →
 28 30 2 30 2 28 30 2 30 2 28 24 2 30 → 2

After adding 60 more cycles (total of 90), no new populations appeared, Figure 10.2.4 .

The system was too conservative because of high C and low H.

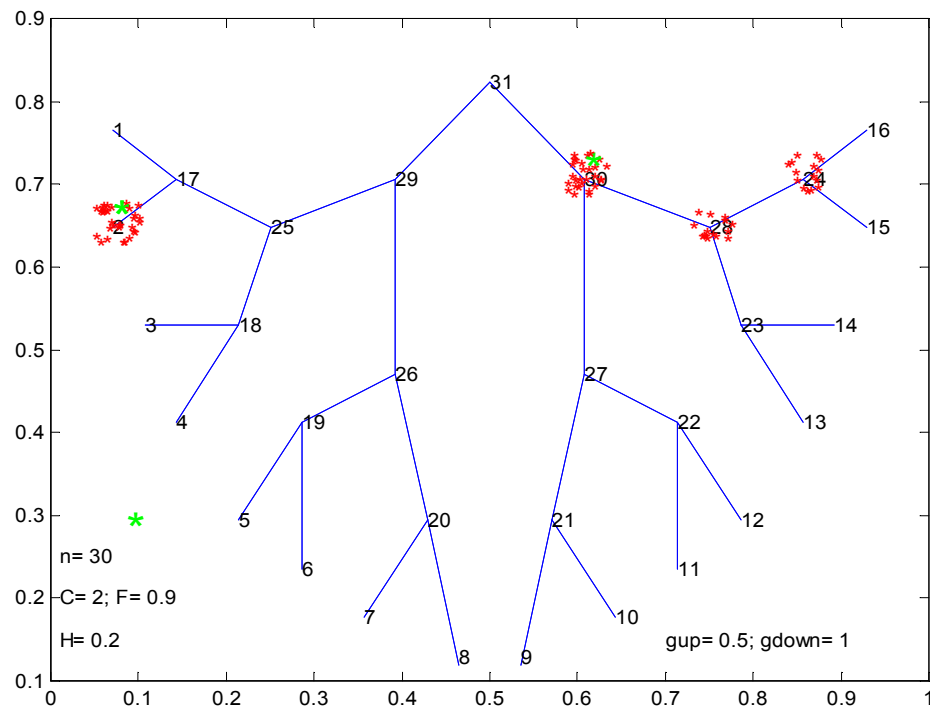


Figure 10.2.4 Two populations of “thoughts” in PROTO; 90 cycles

Next, in the CONTINUE mode, the parameters were changed to: $C = 0.5$, $H = 0.5$, $F = 0.5$. Figure 10.2.5 shows the immediate scattering of one of the populations. After 120 cycles, however, PROTO still remembers its original acton 2, but keeps exploring its second area of the connector.

Trajectory: tra = 30 → 2 28 24 2 28 2 21 23 2 21 2 27 22 27 →
21 22 27 2 22 2 27 2 21 22 24 23 22 2 → 21

Finally, Figure 10.2.6 illustrates two populations formed at a different, less relaxed set of parameters: $n=30$, $a=2$, $F=0.8$, $C=1$, $H=0.5$.

Trajectory: tra = 8 2 18 27 2 27 2 27 2 27 2 27 2 27 18 2
22 2 22 18 22 2 22 18 2 22 2 18 22 18

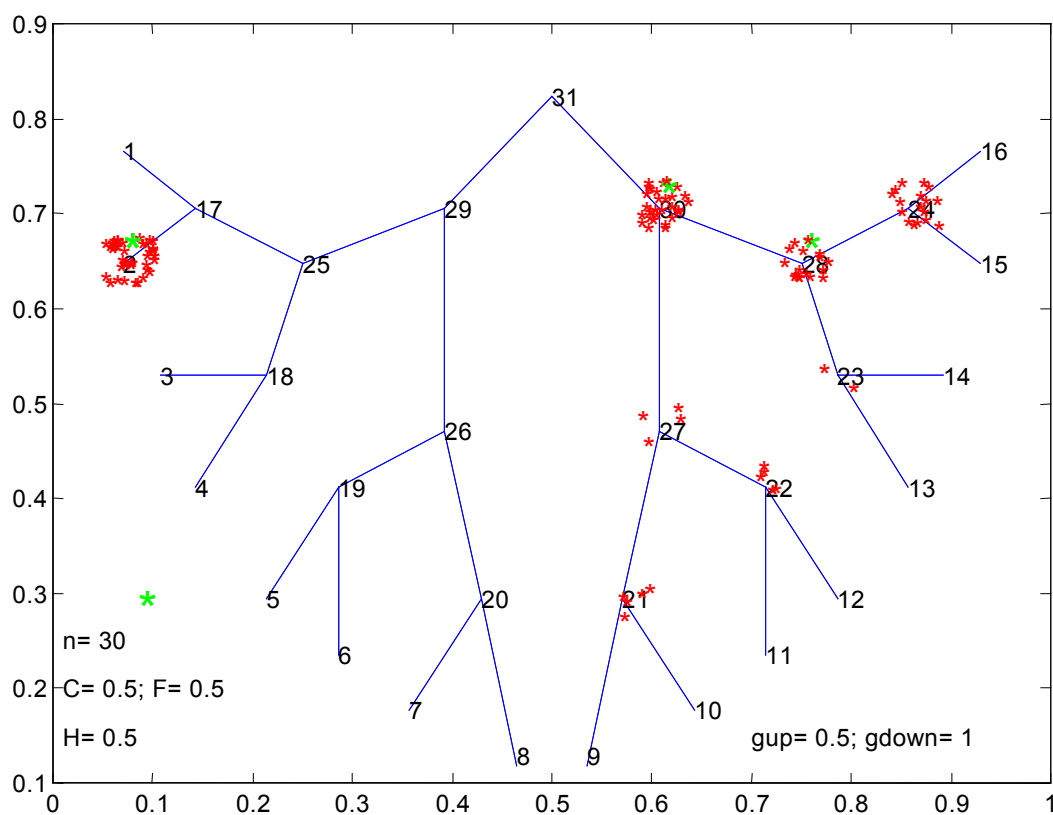


Figure 10.2.5 Two populations of “thoughts” in PROTO; relaxed parameters, 30 new cycles

In this series, node 8 was the initial acton (after 2), but the populations there did not put roots. The bridge 17—25 between nodes 2 and 18 remains, so to speak, subconscious.

The absence of limits imposed by percolation, i.e., possibility of jumps over the connector, seems to be the most striking property of the model. The jumps between distant nodes can be regarded as an evidence of dynamic memory or, in terms of the science of complexity, emergent behavior. **PROTO remembers its initial acton for a long time, although it is not stored anywhere explicitly.**

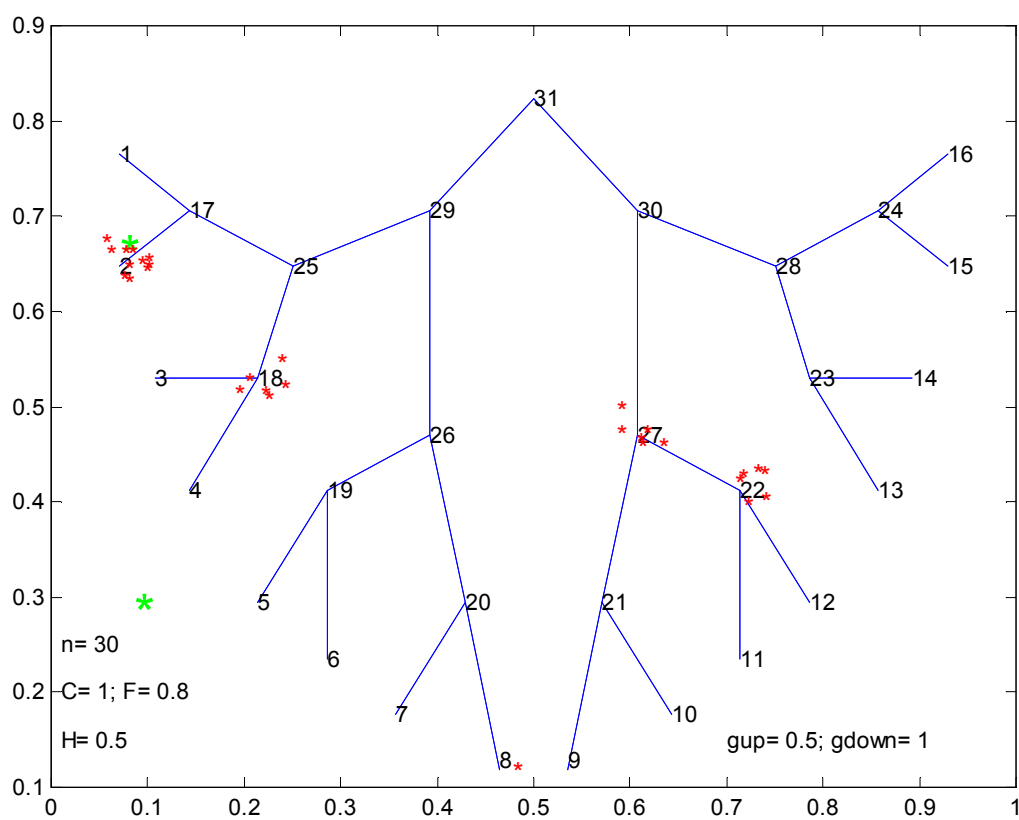


Figure 10.2.6 Three populations of “thoughts” after 30 cycles

There is the famous problem of the origin of elephant's trunk: when it is small, it is of no use, when it is large, it cannot be explained by small mutations. Of course, there is Rudyard Kipling's explanation, but it is quite a stretch. The jumps in PROTO suggest that if the genome is organized as the scale of sets, then mutations can happen in such a way that the whole block of phenotype changes.

Discussion

After many experiments, which would take too much space to report here, a conclusion could be drawn that the system manifests a rather rich behavior, depending on parameters. Even though the experimental generator space was small, the continuous multidimensional **parameter** space was large. An unexpected problem (probably, common for all virtual models) was the temptation to explore this primitive model and to play with it, instead of building a more complex and realistic one. Before the expansion could be done, some preliminary observations may be of interest.

Even if we do not know what exactly consciousness is, we can tentatively answer what the subconscious is. We select in PROTO only the most probable candidate for the focus of consciousness, but we can compile a list of runner-ups, as in a beauty contest, with decreasing probability. Technically, we can do it by casting a random number over the distribution of probability remaining after the previous selection, collapsing the winning probability segment to zero and starting a new selection. Those subconscious levels of thinking form the subconscious bulk of the mental iceberg. They may or may not influence our thinking, which normally is mostly conscious, but not quite, and we do not even know to what extent because, by definition, we cannot see beyond the focus of consciousness.

We shall also attempt to answer the question why we need consciousness at all and what its biological role is.

In short, why are we able to describe something observable (a grazing horse) and convey it? We are able—involuntarily, because of the design of our mind where only one or two thoughts can come to consciousness at a time—to separate the thoughts *horse* and *graze* as

consecutive thoughts and, therefore, separate and express as consecutive terms of the sentence. The same is even more true about describing complex and extended in time events. Since the content of consciousness is ordered in time, it is ordered in speech. Consciousness makes the parsing of reality possible. It is a condition for an analytical mind.

One could see a deep analogy with the mechanism of ribosomal synthesis of a peptide over the RNA script. The ribosome selects one nucleotide triplet at a time, being “unconscious” about the rest. Of course, there is not much entropy in following the 1D Ariadne’s thread.

Language is a social phenomenon, understanding of an utterance is expected, and wherever we have communication between two animals or people about an external object, we may suspect a form of consciousness. A bird’s song or a lion’s roar communicate, probably, only the internal states of the animals, as a cell phone communicates a low battery or end of charging, but a warning shriek of a monkey seeing a predator seems to indicate consciousness and language.

Consciousness spontaneously scans the content of the mind, converting it into a linear sequence of states. As we suggested earlier, the fact of understanding is confirmed by the act of the communication of the result of understanding to somebody else. **Consciousness, therefore, is a more technical than mystical term.** The geese that saved Rome manifested their patriotic consciousness in their warning cries.

Spontaneous thinking, in chemical terms, is an autocatalytic process, like life itself. The mathematics and physics of such processes were explored in detail by Ilya Prigogine, Manfred Eigen, and others, especially, around the Santa Fe Institute of Complexity. Order (new knowledge) is created in such systems because of the inflow of Gibbs energy and dissipation of most of it as heat. The difference is retained as order. In our model, the forgetting embodies the loss in the form of dissipation, and novelty creates new order. The conflict between the old and the new creates information.

The next step of development of this model should be formation and extinction of bonds and nodes as result of **spontaneous** activity, in other words, generation of new knowledge by

pure invention and mental game—not acquisition, because there would be no external source. It could go through stressed transition states created by an imposed problem.

Our modest model alone does not justify the above far-reaching conclusions, hypotheses, and mere fantasies, but it may point to a rewarding direction of “artificial natural” intelligence. Following this idea, we may stumble at a definition of consciousness, for example, but we are not forbidden to look for its abstract foundations even without knowing what exactly it means as a chemical and physical phenomenon.

In our model, no homunculus is required. The algorithm of natural selection is all we need. The system behaves as a non-linear cellular automaton. It is not a learning neural network because it gives no functional output. To see how a useful function could be built on the platform of spontaneous activity is our future task.

Even if we design a humanoid utterly clever, we may confront unforeseen consequences that would conflict with our design. We must part with our creation, giving it the last touch, as in the fresco by Michelangelo. Moreover, we should expect it to discover forbidden knowledge and to revolt against its creator, as the image of Golem suggests.

11. SCALE

Both BIRDS and PROTO are Ar-systems because their generator space and connector remain fixed. The purpose of SCALE is to simulate evolution of a He-system from zero, exploiting the property of *novelty*.

The MATLAB program SCALE builds a record of its inputs (*history*) in the form of matrix WORLD, which is a sub-scale of sets, partially ordered along time axis. Time here is the discrete Leibniz time, i.e., the ordered set of events (“... time is an order of successions,” [21], p.25). Time does not move if nothing happens.

Recall again that in the scale of sets, each configuration is also a generator. WORLD is the connector graph, the nodes of which are generators. Therefore, WORLD is a configuration. Each generator has a unique *name*, which can be a word or a number. The name is just a symbol and is extralinguistic: it is not necessarily a word or symbol of an existing language. SCALE stores the sequence of names in the order of their issue.

In the beginning of the *history* of WORLD, the generator space contains a single “empty” generator with the name ‘!’.

SCALE works in the following sequence of stages (examples of inputs are in square brackets).

1. SCALE displays:

1 to start, 2 to continue [1]

Once started by typing 1, it can be continued with the same WORLD by typing 2. Typing 1 erases the previous WORLD.

2. It asks for the number of cycles in the session by prompting:

nn [16]

3. It prompts:

enter components ['1 8 7'] or ['cat dog']

Components must be entered interspaced and as a single character string.

4. If the input cannot be found in WORLD:

This is new. Name it [']' or ['pet']

5. If the input is a single generator and can be found in WORLD as single generator, the output is:

This is old

If the input is a set of generators, for example, 'l e o n' (spaced) the program asks:

Looks like W32: Leon

Is it new? 1/0

[0 (i.e., no)]

Output **Looks like** means that WORLD contains a permutation of the input, for example N o e l. SCALE distinguishes between 'a b c d', 'c a d b', and 'abcd'. The first two are sets of four signs, while the third is a single name, for example, the name for the first.

Suppose, we enter 'N o e l' and get the same response:

Looks like W32: Leon

Is it new? 1/0

[1 (i.e., yes)]

If so, SCALE will ask for a name, which can be entered as 'Noel.'

This feature is intended to simulate, in a simplified form, the coding of configurations, with similarity transformation PERMUTATION, as a model of more complex transformations, for example, SIZE.

When a new generator enters WORLD, it is always either new single or a new combination of old ones. The connections between members of the combination and the name are stored in the WORLD matrix, expanding the connector. Therefore, throughout the *history* of WORLD, both generator space and connector change.

The following example of a gradually created small world illustrates the variety of possible WORLDS. The WORLD (fragmentary) contains the words in English, Swedish, Russian, and Latin, Figure 11.1. The top line is the base of the scale of sets.

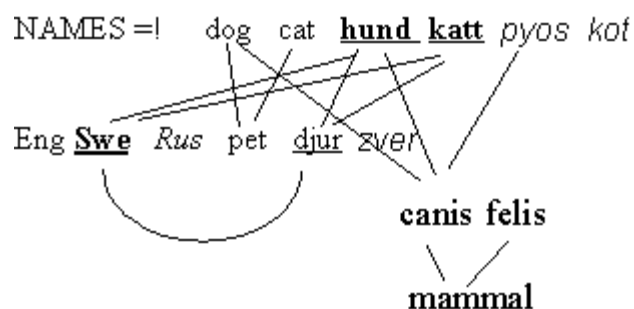


Figure 11.1 Example of a polylingual WORLD with five sub-WORLDS: four languages and biotaxonomy (incomplete).

Figure 11.2 presents a WORLD in 3D. It portrays some relationships between characters of TV sitcom *Providence*. The model was suggested by Ulf Grenander.

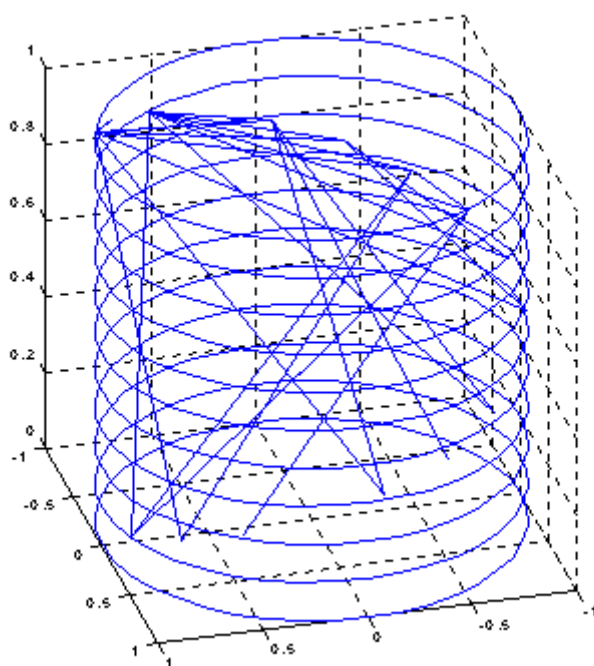


Figure 11.2 The WORLD of a TV sitcom in 3D. History runs along Z axis.

Axis Z is the *historical time*, i.e. the sequence of building the WORLD.

In figure 11.3 the same WORLD is projected on the plane of the base set.

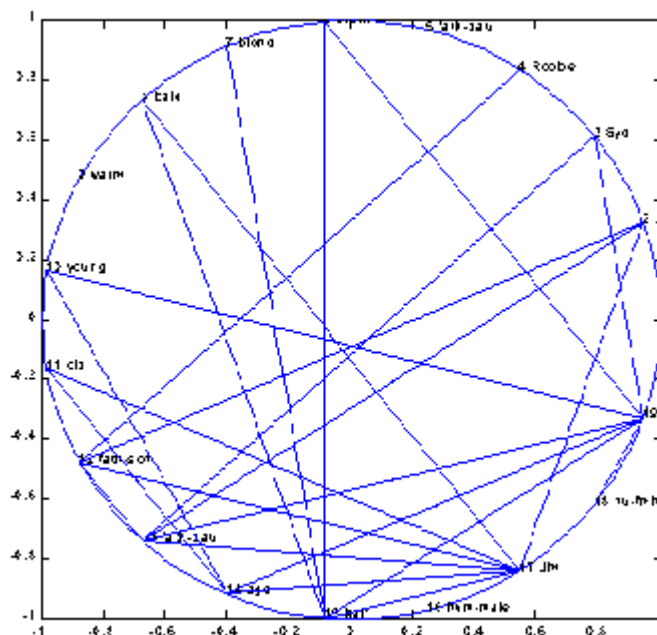


Figure 11.3 The WORLD of Figure 11.2 in 2D

SCALE does not need a teacher or instructor because the names are not essential. The main property to be recognized for the evolution of the WORLD is novelty. WORLD, therefore, reflects not only a certain artificial or natural world, but also the history of the presence of the internal WORLD in the external world. The old is recognized, while the new is remembered.

The WORLD “LINES” is built in the following way.

Nine cells of a mini-retina are numbered as in Figure 11.4. Cell 9 is the empty generator.

1	2	3
8	9	4
7	6	5

Figure 11.4 Numeration of cells in a mini-retina

The WORLD fills up first with individual cells from 1 to 9 , named from '1' to '9' and then their combinations. For example, X is a combination of / and \. The following is a slightly re-formatted actual output.

```

enter components      '1 8 7'
This is new. Name it  '['
enter components      '3 4 5'
This is new. Name it  ']'
enter components      '1 2 3'
This is new. Name it  '~'
enter components      '7 6 5'
This is new. Name it  '_'
enter components      '1 9 5'
This is new. Name it  '\ '
etc.

```

In Figure 11.4, letters are formed out of simpler subsets of the retina.

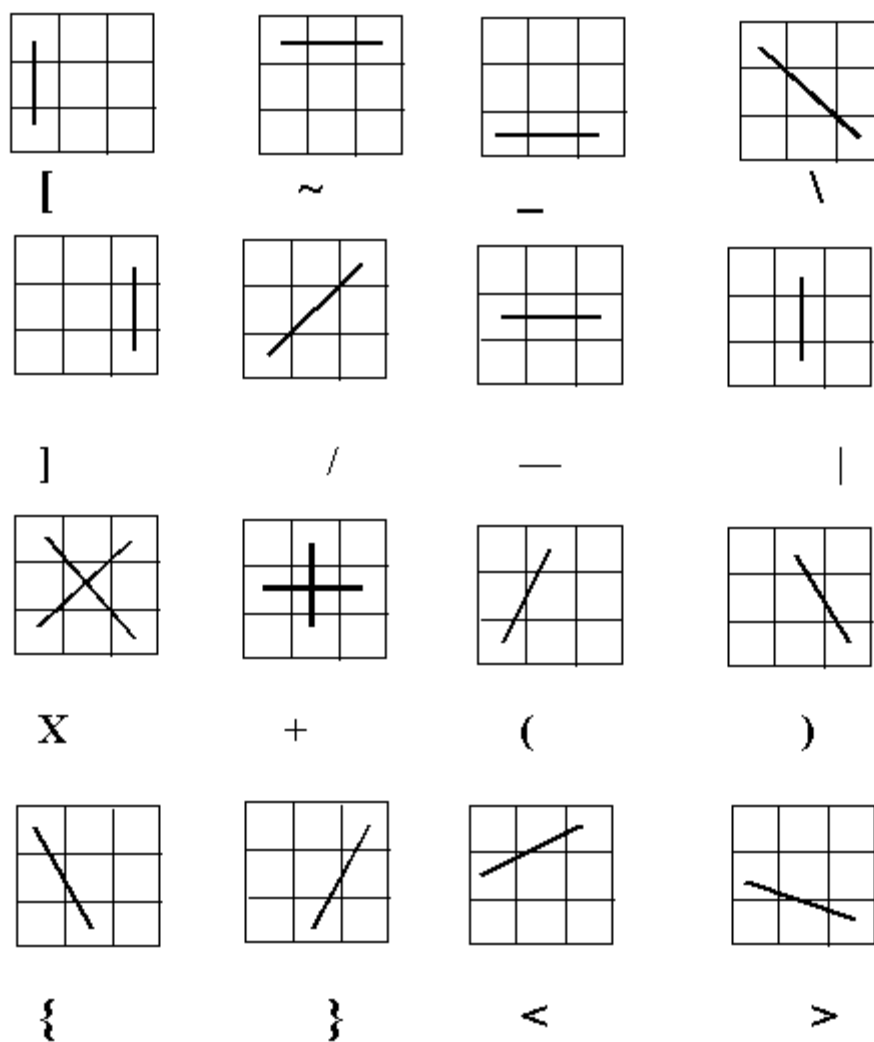


Figure 11.4 Formation and naming of retina subsets

Next, the triplets of the cells and larger retina subsets are combined and named, see Figure 11.5.

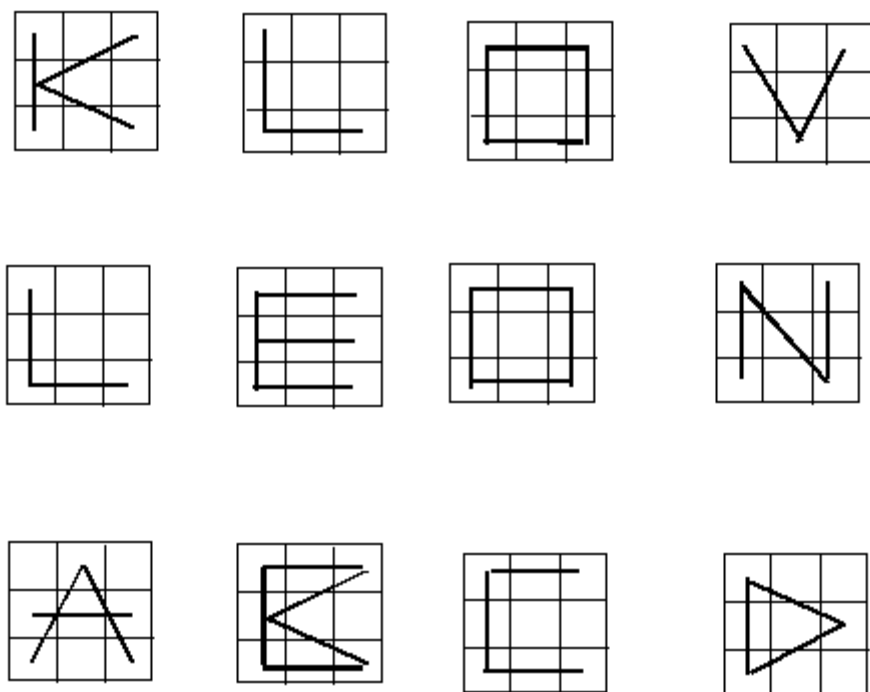


Figure 11.5 Letters formed from lines

Figure 11.6 presents two projections of the WORLD “LINES” built on the base set of nine pixels.

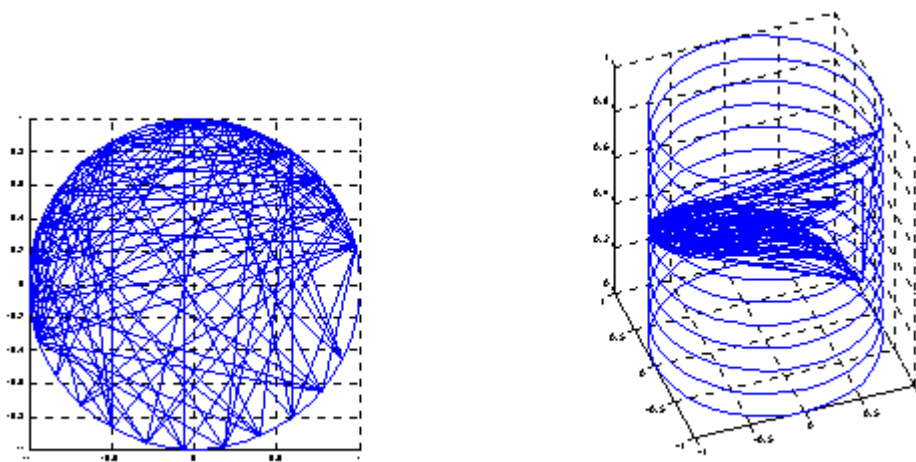


Figure 11.6 Projections of the WORLD of LINES

Figure 11.7 presents the flat and 3D projections of the WORLD of PROTO, built with SCALE, node by node from 1 to 31.

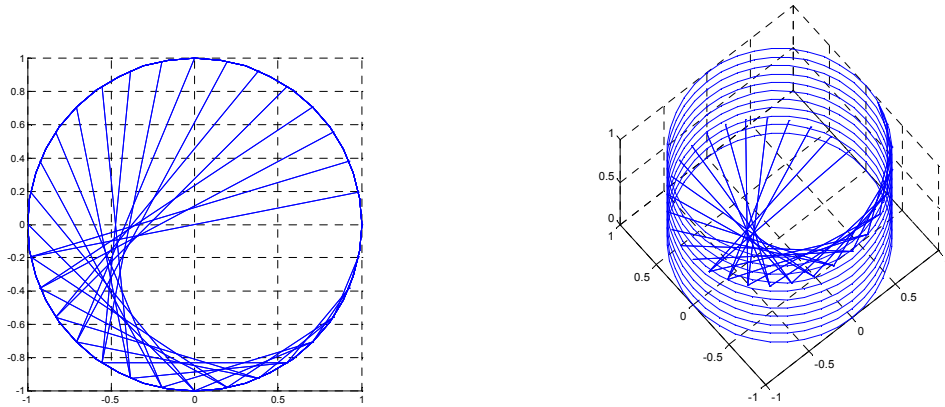


Figure 11.7 Projections of the WORLD of PROTO

SCALE has some mini-utilities:

1. If you want to check WORLD for a name, type: `link`
2. To see NAMES, type: `NAMES` (or `NM`)
3. To display the 3D world, type `plotW`

Of course, the WORLD matrix (WW) can be displayed, too, for example, as sparse matrix `sparse(WW)`.

Program LINK gives the complete *spectrum* of an old generator, listing its name and all its entries in the WORLD, i.e., downward and upward connected generators, for example:

» `link`

NAME to check 'x'

/ \

Also, for more complex combinations:

» link
 NAME to check 'K'
 / E L O X [\

» link
 NAME to check '/'
 ! - 3 7 < > K X [\] _ | ~

» link
 NAME to check '~'
 / 1 2 3 < > E O T [\] |

The generator space for the WORLD in figure 11.6 is

NAMES = ! 1 2 3 4 5 6 7 8 | - \ / [] ~ _ X T + E L O K < > (size 28)

If desired, the spectrum can be split into up and down entries, the entries of new samples of an old type can be made, but not in this program.

Evolution of a MIND where a WORLD is being built is a separate subject. In short, with time, most of the WORLD is forgotten, but part of it turns into KNOWLEDGE, i.e., a flat WORLD, as in Figure 11.6 (left), is stored in the long-term memory. Probably, the entries compete for the place in KNOWLEDGE, too. Even the bees do it.

Conclusion

The following propositions have been combined in this paper:

1. **Ulf Grenander**: Objects in the mind (“thoughts” or “ideas”) are configurations within the framework of Pattern Theory. This thesis, for the first time, was used by Ulf Grenander for the groundwork in building a model of the mind that does not ignore its complexity. The model demonstrates properties similar to those of chemical systems in equilibrium.
2. **Henri Poincare**: Objects in the mind (“thoughts”) compete for the place in consciousness.
3. **Manfred Eigen**: Darwinian competition of linear sequences in the sequence space follows formal chemical kinetics. This proposition can be generalized to configurations in the sense of PT.
4. **Chemical kinetics** is based on the concept of transition state. This proposition can be generalized to irregular configurations in the sense of PT, which closes the cycle of the four propositions at a different level and returns us to Proposition 1.
5. **Bourbaki**: A simple system can expand as the scale of sets toward unlimited complexity. From the concept of the scale of sets, the distinction between Ar- and He-complexity was suggested.

The described models are just some toys to play with while designing a mind that would connect AI with NI. Some of their meaningful properties, however, can be seen even at their embryonic stage. Thus, they do not require any sweep strategy: they are self-sweeping (or self-

scanning). If realized as parallel systems of cellular automaton type, they do not require any numbering of their generators. Neither do they need to store any large arrays. In other words, they are homunculus-free. It is the same as to say that they belong to NI as much as to AI.

Further, the models can have a limited number of global parameters and an unlimited number of simple local nodes. Notably, the size of SCALE, as the size of human brain, does not depend on the size of the world it stores, perceives, and processes, while the world expands. This means, most important, that they are contractible, metaphorically speaking, in the sense of homotopy theory: the large system can be reduced to zero volume without any change in the algorithm. Conversely, a small system can be expanded as a homotopy. Even more important, the expansion due to the interaction with environment can occur, up to a point, in an autonomous way, as self-learning based on the distinction between the old and the new.

Homunculus wears two hats in AI: as internal operator and external teacher. The models in this paper avoid homunculus by making the core of the program so simple that it can be entrusted for execution to a single cell in a cellular automaton in the most general sense.

This treatise, inclusive of such subjects as AI and chemistry, as well as vacuum cleaners, poems, and bees, seems to deal with very different worlds. World is a useful axiomatic concept that cannot be defined. A tentative classification of worlds can be suggested:

Real	RW
natural	RNW
artificial	RAW
Virtual	VW
real	VRW
unreal	UVW

The virtual real world is a simulation based on observable principles, for example, for scientific purposes, while the virtual unreal world, for example, a simulated transformation of a man into a vampire, is based on arbitrary or highly hypothetical principles.

Stephen Spielberg's film *Artificial Intelligence*, unlike such films as *Lord of the Ring*, tries to preserve realism of the laws of nature for at least half the film, given the basic premise of the plot. Both brilliantly told tales, regardless of their message, illustrate the difference between real and unreal virtual worlds. At the same time, both preserve realistic patterns of human behavior and attitudes.

The borderlines between the worlds are not strictly defined and a theory of worlds regarding the above distinctions could be an independent subject.

The next steps in moving along the pathways sparsely marked in this paper could be:

1. The WORLD where generators compete for presence, while fading due to forgetting boosted by the lack of retrieval, and being revitalized due to subsequent referrals. This presumes a contact with environment. The process of the transformation of the world as history (Figure 12.2) into the world as knowledge (Figure 11.3) is of particular interest.

2. Simulation of the environment that imposes its own order on the spontaneous activity of the mind. This was attempted with PROTO by forced activation of generators and, of course, had the expected effect.

3. Creation of autonomic agents that may have a preset perception systems (vision, hearing), but are self-learning in the sense that they build their internal WORLDS without a teacher, through distinction between new and old. For example, a baby Roomba can be created, which explores the environment and creates its WORLD before going into the stage of maturity where success and failure are reinforced and discouraged, accordingly, by "good girl!" and "stop it!"

A preset (inborn) system of perception for vision, for example, could use various similarity transformations on two-dimensional lattices. PT provides an ideal theoretic apparatus for that.

This could generate extralingual **pattern** outputs, such as, for example, named for convenience in English “line,” “L-shape,” “human face,” “grass,” etc., ready for entering the WORLD where PERMUTATION is, most probably, the only feasible transformation. There is no physical movement in the brain comparable with the powerful transformations of the eye movements.

4. Transition from extralingual WORLD to language, which is, probably, just a reversed SCALE: not from inputs to the world but from WORLD to linguistic outputs. Ulf Grenander’s model offers well-tilled soil for that.

5. Fine chemistry of thoughts that follows the mechanism of transition from regular thoughts to new regular thoughts through an irregular transition state.

Pattern kinetics and **pattern history** seem to be other directions worth exploring. Author and Ulf Grenander have made some steps toward pattern theory of history in their unpublished manuscript *History as Points and Lines*, from which Figures 5.3 and 5.4 were reproduced. Some rich food for pattern thought can be found in the new book by Bertrand Roehner and Tony Syme *Pattern and Repertoire in History* [22]. *The Sociology of Philosophies: A Global Theory of Intellectual Change* by Randall Collins [23] is a striking intellectual adventure in the pattern spirit where the competition of ideas is in the focus. Even the title of the first chapter, “*Coalitions in the Mind*,” gives the taste of the whole, the chapter starting with:

Intellectuals are people who produce decontextualized ideas. These ideas are meant to be true or significant apart from any locality, and apart from anyone concretely putting them into practice. A mathematical formula claims to be true in and of itself, whether or not it is useful, and apart from whoever believes it.

Randall Collins [23], p.20

Another proposition, expressed by the author and Ulf Grenander in *History as Points and Lines* states that the apparatus of the Internet, for the first time in history, opens the possibility to actually measure the state of the real world close to the real time, its position on the

“globescape,” and to follow its transition states. Similar idea was expressed in another highly relevant and fundamental book by Bertrand Roehner, *Patterns of Speculation*, [24], p. xv. Of course, the same can be done on any sub-world, such as economics or even arts. The latter offers a rich array of irregularities and transient modes.

Chemical knowledge at any particular moment is an Ar-system, for which history is irrelevant. It represents part of the real world of molecular structures known today. As a creation in human mind, however, chemistry has a history coded by references in chemical literature, as well as in CAS registry. No philosophic position is required to appreciate this fact because both chemistry and its history are **observable** objects. The collective human mind builds both systems, day by day. Chemistry here is just an example, and AI or football can be substituted for it.

Traveling back to the small but dense world of ancient AI, we may discover there a richness of vision lost today among the vast expanses.

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MINDSCALE MATLAB codes are available from: **APPENDIX** to Molecules and Thoughts

[doc](#) [pdf](#) [zip](#) (<http://spirospero.net/mindscale-codes> .doc , .pdf , or .zip)

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APPENDIX to:

Molecules and Thoughts

Pattern Complexity and Evolution in Chemical Systems and the Mind

<http://spirospero.net/mindscale.pdf> ; <http://spirospero.net/MINDSCALE.pdf>

<http://www.scribd.com/doc/11576667/-Yuri-Tarnopolsky-MOLECULES-AND-THOUGHTS>

Yuri Tarnopolsky

PROTO

WORKSPACE: [PROTO.mat](http://spirospero.net/PROTO.mat)

<http://spirospero.net/PROTO.mat>

The MATLAB program PROTO requires workspace **PROTO.mat**, is stored as scripts **proto.m** (main), **proto1.m**, and **proto2.m**, and generates a figure of the tree with red asterisks meaning acts of selection (actons).

To activate the program, save workspace (matrices **P**, **T**, and **GXY**) and the scripts. The main program offers a choice of starting from equal probability distribution (proto1) or continuing from the previous workspace, parameters, and probability distribution (proto2).

proto.m

%PROTO; script proto; can be renamed

```
S=input('1 to start, 2 to continue ');
```

```
if S==1
    proto1
end
if S==2
    proto2
end
```

proto1.m

%PROTO1; TO START; file proto1.m; workspace proto.mat

%SETS PARAMETERS AND STARTS FIRST BATCH

% can be followed by proto2.m

%Workspace: P(32x11), T(31x31), GXY (31,2).

%Initial settings:

H=0.7; F=0.9; C=1; gup=0.5; w=2; a=2; t=0.1;

%%%%%%%%PARAMETERS SECTION %%%%%%%%%%

n=input('Enter n ');%n=20;

a=input('Enter a ');% a=2;

%b=input('Enter b '); %Optional second acton

F=input('Enter F ');%F=0.8;

C=input('Enter C ');%C=1;

H=input('Enter H ');%H=0.8;

%gup=input('Enter gup ');

gup=0.5;

%w=input('Enter w ');

w=2;

gdown=w*gup;

%gdown=input('Enter gdown ');

%gdown=2;

%t=input('Enter pause t ');

%t=0.1;

tra=[]; % tra: trajectory

ar=0; %ar: arity

aa=a; %aa: cell for the previous acton;

%%%%%%%% END of PARAMETERS SECTION

%%%%%%%%

PAR12=['a=',num2str(a)];

text(0.01,0.3,PAR12); %displays starting acton

PX=P(1:31,2)/14; PY=P(1:31,3)/8.5; P(32,7)=0;

%factors 14 and 8.8 to fit the figure

%COLUMNS in matrix P: 1: Node #; 2,3: Node coordinate, 4-6: Node neighborhood;


```

% 7: Probability,p; 8: Influence,v; 9: Active node,A; 10: Memory,M;
%11: Spare column. Line 32:zeros.

%INITIAL MATRIX P. Equal probabilities.
    P(1:31,7)=1/31; P(:,8:11)=0; %Columns 7 to 11 contain variables

% Data for the acton:
P(a,7)=C; P(a,9)=1; P(a,10)=C;%ACTON ENTERED

AA=zeros(n,1); %array for the trajectory prepared;
                                %contains subsequent actons

%%%%%%%%%%%%% DISPLAY SECTION %%%%%%%%%%%%%%
%CONNECTOR GRAPH DISPLAY
    gplot(T,GXY);

%NODE NUMBERS DISPLAY;
    for i=1:31
        No=int2str(i);
        text(PX(i), PY(i), No );
    end
%ACTON ASTERISK DISPLAY
    text(PX(a),PY(a)+0.01,'*','color',[0 1 0],'FontSize',24);

    %text(PX(b),PY(b)+0.01,'*','color',[0 1 1],'FontSize',24);
    % b is the optional second acton

%PARAMETERS DISPLAY
PAR1=['n= ',num2str(n)]; PAR11=['H= ', num2str(H)];
PAR2=['C= ',num2str(C),'; F= ',num2str(F)];
PAR3=['gup= ',num2str(gup),'; gdown= ',num2str(gdown)];
text (0.01,0.25,PAR1);
text (0.01,0.2,PAR2);
text(0.07, 0.28,'*','color',[0 1 0],'FontSize',24);
text(0.7,0.15,PAR3);text (0.01, 0.15,PAR11);

%%%%%%%%%%%%% END OF DISPLAY SECTION
%%%%%%%%%%%%%

%PROTO CONTINUES, PR STARTS; PR adds n cycles.

for jj=1:n

% START MEMORY
    for ii=1:31
        P(ii,10)=F*P(ii,10);

```

```

end
P(a,10)=F*C; P(a,7)=C;%special values for the acton

% END MEMORY

%START INFLUENCE

P(a,7)=H*C; %to exert influence

P(:,8)=0;
for I=1:31
    for j=4:6
        if P(I,1)<P(I,j)
            g=gdown; else g=gup;
        end
        if I<16 ar=1; end
        if I>16 & I<31 ar=1/3; end
        if I==31 ar=1/2; end

        %P(I,8)=P(I,8)+P(P(I,j),7)*g*ar;
        %previous influence remembered
        P(I,8)=P(P(I,j),7)*g*ar;
    end
end
%END INFLUENCE
%START PROBABILITY
P(a,7)=C; %just a formality
for I=1:31 P(I,7)=P(I,7)+P(I,8)+P(I,10); end

%%%%%%%%%%%%%%
%END PROBABILITY

% START    ACTON SELECTION

P(a,7)=0; %cannot be selected again
SUM=0;
ss=0; S=P(1:31,7); SUM=sum(S); P(1:31,7)=P(1:31,7)/SUM;
r=rand;
for i=1:31, ss=ss+P(i,7);
    if ss>r, a=i; break,
end
end
P(:,9)=0;P(a,9)=1; %information about acton; not used
P(aa,7)=C; %probability for the previous acton;
% END ACTON SELECTION

```

```

% ACTON ASTERISK DISPLAY; Randomization of the position of ASTERISK.
    %This is done redundantly,with possible other uses in mind
    %COORDINATES
    LXx=P(1:31,2);LX=LXx'/14;
    LYy= P(1:32,3);LY=LYy'/8.5;

    for I=1:31
    %RANDOM SHIFT OF X
    u=rand/40;
    %RANDOMIZATION OF SIGN
    uu=rand; if uu<=0.5, uuu=1; else uuu=-1; end
    u=u*uuu; LX(1,I)=LX(1,I)+u; end
    for I=1:31
    %RANDOM SHIFT OF Y
    u=rand/40;
    %RANDOMIZATION OF SIGN
    uu=rand; if uu<=0.5, uuu=1; else uuu=-1; end
    u=u*uuu; LY(1,I)=LY(1,I)+u; end

    text(LX(a), LY (a), '*', 'color',[1 0 0],'FontSize',12);
%END ASTERISK DISPLAY

    % END OF PROTO FOLLOWS
pause (t);
a;AA(jj,1)=a; tra=AA';
end
PP=zeros(31,2);PP(:,1)=P(1:31,1); PP(:,2)=P(1:31,7);
disp ('type PP for probability distribution ');
disp ('type tra for trajectory');

```

proto2.m

```

%PROTO2; TO CONTINUE; file proto2.m; workspace proto.mat
%CONTINUES WITH PREVIOUS WORKSPACE AND
%PROBABILITY DISTRIBUTION; Prompts for n
%%PROTO2 is done redundant,with possible other uses in mind

%Workspace: P(32x11), T(31x31), GXY (31,2).

%%%%%%%%%%PARAMETERS SECTION %%%%%%%%%%%
n=input ('Enter n ');          %n=20;

%a=input('Enter a ');% a=2; %F=input('Enter F ');%F=0.8;
%C=input('Enter C ');%C=1; %H=input('Enter H ');%H=0.8;

```

```

%gup=input('Enter gup ');%gup=0.5;
%w=input('Enter w ');%w=2; %gdown=w*gup;
%t=input('Enter pause t ');%t=0.1;

tra=[];          % tra: trajectory

%%%%%%%%%%%%^^^ END of PARAMETERS SECTION
^^^%%%%%%%%%%%%

%COLUMNS in matrix P: 1: Node #; 2,3: Node coordinate, 4-6: Node neighborhood;
% 7: Probability,p; 8: Influence,v; 9: Active node,A; 10: Memory,M;
%11: Spare column. Line 32:zeros.

%INITIAL MATRIX P. Equal probabilities.
    %P(1:31,7)=1/31; P(:,8:11)=0; %Columns 7 to 11 contain variables

    % Data for the acton:
    P(a,7)=C; P(a,9)=1; P(a,10)=C;%ACTON ENTERED

    AA=zeros(n,1); %array for the trajectory prepared;
                                %contains subsequent actons

%%%%%%%%%%%%%%DISPLAY SECTION %%%%%%%%%%%%%%%
%CONNECTOR GRAPH DISPLAY
    %gplot(T,GXY);
%NODE NUMBERS DISPLAY;
    %for i=1:31
    %No=int2str(i);
    %text(PX(i), PY(i), No );
    %end
%NEW ACTON ASTERISK DISPLAY (THE ACTON LEFT BY PROTO1)
    %text(PX(a),PY(a)+0.01,'*','color',[0 1 0],FontSize,24);

    rectangle ( 'Position', [0, 0.1, 0.12, 0.25], 'FaceColor', 'w')
    rectangle ( 'Position', [0.7, 0.1, 0.3, 0.1], 'FaceColor', 'w')

    %PARAMETERS DISPLAY
    PAR1=['n= ',num2str(n)];
    PAR11=['H= ', num2str(H)];
    PAR2=['C= ',num2str(C)];
    PAR22=['F= ',num2str(F)];
    PAR3=['gup=',num2str(gup),'; gdown=',num2str(gdown)];
    text (0.01,0.27,PAR1);
    text (0.01,0.22,PAR11);
    text (0.01,0.17,PAR2);
    text (0.01, 0.12,PAR11);

```

```
text(0.72,0.15,PAR3);
%%%%%%%%%%^^^ END OF DISPLAY SECTION
^^^%%%%%%%%%
```

```
%PROTO CONTINUES, adds n cycles.
```

```
for jj=1:n
```

```
% START MEMORY
```

```
    for ii=1:31
```

```
        P(ii,10)=F*P(ii,10);
```

```
    end
```

```
    P(a,10)=F*C; P(a,7)=C;%special values for the acton
```

```
% END MEMORY
```

```
%START INFLUENCE
```

```
                P(a,7)=H*C; %to exert influence
```

```
    P(:,8)=0;
```

```
    for I=1:31
```

```
        for j=4:6
```

```
            if P(I,1)<P(I,j)
```

```
                g=gdown; else g=gup;
```

```
            end
```

```
            if I<16 ar=1; end
```

```
            if I>16 & I<31 ar=1/3; end
```

```
            if I==31 ar=1/2; end
```

```
    %P(I,8)=P(I,8)+P(P(I,j),7)*g*ar;
```

```
    %previous influence remembered; optional
```

```
    P(I,8)=P(P(I,j),7)*g*ar;
```

```
        end
```

```
    end
```

```
%END INFLUENCE
```

```
%START PROBABILITY
```

```
P(a,7)=C; %just a formality; will be zero anyway
```

```
    for I=1:31 P(I,7)=P(I,7)+P(I,8)+P(I,10); end
```

```
%%%%%%%%%%
```

```
%END PROBABILITY
```

```

% START      ACTON SELECTION
    P(a,7)=0; %cannot be selected again
    SUM=0;
    ss=0; S=P(1:31,7); SUM=sum(S); P(1:31,7)=P(1:31,7)/SUM;
    r=rand;
    for i=1:31, ss=ss+P(i,7);
        if ss>r, a=i; break,
    end
end
P(:,9)=0;P(a,9)=1; %information about acton; not used
P(aa,7)=C; %probability for the previous acton;
% END ACTON SELECTION

```

```

% START ACTON ASTERISK DISPLAY;
%Randomize the position of ASTERISK.

```

```

    %COORDINATES
    LXx=P(1:31,2);LX=LXx'/14;
    LYy= P(1:32,3);LY=LYy'/8.5;

    for I=1:31
        %RANDOM SHIFT OF X
        u=rand/40;
        %RANDOMIZATION OF SIGN
        uu=rand; if uu<=0.5, uuu=1; else uuu=-1; end
        u=u*uuu; LX(1,I)=LX(1,I)+u; end
    for I=1:31
        %RANDOM SHIFT OF Y
        u=rand/40;
        %RANDOMIZATION OF SIGN
        uu=rand; if uu<=0.5, uuu=1; else uuu=-1; end
        u=u*uuu; LY(1,I)=LY(1,I)+u; end

    text(LX(a), LY (a), '*', 'color',[1 0 0],'FontSize',12);
%END ASTERISK DISPLAY

```

```

    % END OF PROTO FOLLOWS
pause (t);
a;AA(jj,1)=a; tra=AA';
end
PP=zeros(31,2);PP(:,1)=P(1:31,1); PP(:,2)=P(1:31,7);
disp ('type PP for probability distribution ');
disp ('type tra for trajectory');

```

BIRDS

WORKSPACE: [BIRD.mat](http://spirospero.net/BIRD.mat)
<http://spirospero.net/BIRD.mat>

To use BIRDS, copy the workspace BIRDS.mat , copy scripts **bf.m** , **bf2.m**, and **bq.m**.

Start by entering **bf**. After that, use **bf2**. For bf2, n=1 to 10 is recommended. In this mode, drastic changes of direction can be observed even after one cycle. However, only after a certain number of cycles (50-100), the system enters the collective mode. In terms of physics, it reaches a steady state far from equilibrium. At C=1, coherence is low, but at C=2 it is clearly seen.

bf.m

```
%SCRIPT bf
%Initial parameters.

nf=0; b=0; q=0; gg=0; gin=0; gout=0;gd=0;q=0; w=0;
SUM=0; s=0; ss=0; S=0; nf=0; gr=0;

%%%%%%%%%. Input:
n=5; d=16;
F=0.5; C=1;H=1; gin=1; gr=0.8; gd=1;
%%%%%%%%%
gout=gin*gr;
FL(:,8)=1/32;
FL(:,33,:)=0;
FL(37,,:)=0;
FL(:,7)=0;
FL(1:36,33,7)=d;
FL(1:36,33,9)= C;
FL(:,9:10)=0;
L(1:36);
```

```

%START
for nf=1:n, for b=1:36

%MEMORY
%[Forget]
FL(b, :,9)= F* FL(b, :,9);
%[update last direction]
FL(b, FL(b,33,7), 9)=C;
FL(b, FL(b,33,7), 8)=H;

%INFLUENCE, INDIVIDUAL
FL(b, :, 10)=0;
for ii=1:32
    gf=abs(ii-FL(b,33,7));
    if gf>17, gf=32-gf; end
    %[gf=distance between directions ]
    if gf==1
        FL(b,33,10)=FL(b,33,10)+ FL(b,ii,8)*gd;
    end

end;

% INFLUENCE, FLOCK
INF=0;
for w=1:32
    for q=2:9

        if FLA(b,1)< FLA(b,q)
            gg=gin; else gg=gout; end

    %[read neighbor's b]
    x=FLA(b,q);

    %x can be 37

    %[read it's d(past){7}]
    xx=FL(x,33, 7);
    %[read it's P]
    PPP=FL(b,w, 8);
    %[correct this Infl {10}]
    PPP=PPP*gg ;
    INF=INF + PPP;
end
FL(b,w,10)= FL(b, w, 10)+PPP;
end

```



```

%PROBABILITY
for ii=1:32
FL(b,ii, 8)=FL(b,ii,8)+FL(b,ii,9)+FL(b,ii,10);
end

FL(b, FL(b, 33,7), 8)=C;

%SELECTION
SUM=0; ss=0;S=FL(b,1:32, 8); SUM=sum(S);
FL(b, :, 8)=FL(b, :, 8)/SUM;
r=rand;
for i=1:32, ss=ss+FL(b,i, 8);
if ss>r, d=i; break,
end
end

%write new d
FL(b,33,6)=d;
end
FL(:,33,7)=FL(:,33,6);FL(b,33,6)=0;
A=FL(:,33,7);gplot(TOP,COORD);
AH=['H = ',num2str(H)];AC=['C = ',num2str(C)];
AF=['F = ',num2str(F)];An=['n = ',num2str(n)];
Ag=['gd = ',num2str(gd)];Agin=['gin = ',num2str(gin)];
Agout=['gout= ',num2str(gout)];
text (1.5,5.5,AC); text (1.5,4.5,AH);
text (1.5,3.5,AF);text (1.5,2.5,Ag);text (1.5,1.5,Agin);
text (3.4,1.5,Agout); text(3.5,2.5,An);
for u=1:36
X=COORD(u,1); Y=COORD(u,2);
AA=A(u);AAA=[' ',num2str(AA)];
text(X,Y,AAA,'color',[1 0 0],'FontSize',14);

end
end

%quiver plot: bq.m
%for ll=1:36, L(ll)=2*pi*A(ll)/32;end
%sL=sin(L);cL=cos(L);sL(37)=[];cL(37)=[];
%quiver(COORD(:,1),COORD(:,2),sL',cL')

%pause(2);
bq; %if blocked, the grid output will be displayed

```

bq.m

```

for ll=1:36, L(ll)=2*pi*A(ll)/32;end
sL=sin(L);cL=cos(L);sL(37)=[];cL(37)=[];
quiver(COORD(:,1),COORD(:,2),sL',cL')

```

bf2.m

```

%%%%%%%%%%%%. Input:
%n=3; d=16; F=0.3; C=2;H=1; gin=1; gr=0.8; gd=1;
%%%%%%%%%%%%

```

```

%START
gout=gin*gr;
FL(:, :, 8)=1/32;
FL(:,33,:)=0;
FL(37, :,)=0;
FL(37, :,)=0;
FL(1:36,33,7)=d;
FL(1:36,33,9)= C;
FL(:, :,9:10)=0;
FL(1:36,33,7)=d;
L(1:36);

```

```

for nf=1:n, for b=1:36

```

```

%MEMORY
%[Forget]
FL(b, :,9)= F* FL(b, :,9);
%[update last direction]
FL(b, FL(b,33,7), 9)=C;
FL(b, FL(b,33,7), 8)=H;

```

```

%INFLUENCE, INDIVIDUAL
FL(b, :, 10)=0;
for ii=1:32
    gf=abs(ii-FL(b,33,7));
    if gf>17, gf=32-gf; end
    %[gf=distance ]
    if gf==1
        FL(b,33,10)=FL(b,33,10)+ FL(b,ii,8)*gd;
    end
end

```

```

end;

```

```

% INFLUENCE, FLOCK
INF=0;
for w=1:32
    for q=2:9

        if FLA(b,1)< FLA(b,q)
            gg=gin; else gg=gout; end

        %[read neighbor's b]
        x=FLA(b,q);

        %x can be 37

        %[read it's d(past){7}]
        xx=FL(x,33, 7);
        %[read it's P]
        PPP=FL(b,w, 8);
        %[correct this Infl {10}]
        PPP=PPP*gg ;
        INF=INF + PPP;
    end
    FL(b,w,10)= FL(b,w,10)+PPP;
end

%PROBABILITY
for ii=1:32
    FL(b,ii, 8)=FL(b,ii,8)+FL(b,ii,9)+FL(b,ii,10);
end

FL(b, FL(b, 33,7), 8)=C;

%SELECTION
SUM=0; ss=0;S=FL(b,1:32, 8); SUM=sum(S);
FL(b,:, 8)=FL(b,:,8)/SUM;
r=rand;
    for i=1:32, ss=ss+FL(b,i, 8);
    if ss>r, d=i; break,
    end
    end

%write new d
    FL(b,33,6)=d;
end
FL(:,33,7)=FL(:,33,6);FL(b,33,6)=0;
A=FL(:,33,7);gplot(TOP,COORD);

```

```

for u=1:36
    X=COORD(u,1); Y=COORD(u,2);
    AA=A(u);AAA=[' ',num2str(AA)];
    text(X,Y,AAA,'color',[1 0 0],'FontSize',14);
end
%DISPLAY PARAMETERS
AH=['H = ',num2str(H)];AC=['C = ',num2str(C)];
AF=['F = ',num2str(F)];An=['n = ',num2str(n)];
Ag=['gd = ',num2str(gd)];Agin=['gin = ',num2str(gin)];
Agout=['gout= ',num2str(gout)];
text (1.5,5.5,AC); text (1.5,4.5,AH);
text (1.5,3.5,AF);text (1.5,2.5,Ag);text (1.5,1.5,Agin);
text (3.4,1.5,Agout); text(3.5,2.5,An);

end
%QUIVER DISPLAY : bq.m

%for ll=1:36, L(ll)=2*pi*A(ll)/32;end
%sL=sin(L);cL=cos(L);sL(37)=[];cL(37)=[];
%quiver(COORD(:,1),COORD(:,2),sL',cL')

%pause(2);
bq; %if blocked, the grid output will be displayed

```

=====.

SCALE

sc.m (main)

```

% PROGRAM SCALE, script sc; RELATED: link; space lin.mat
% 1. INITIALIZE

S=input('1 to start, 2 to continue ');
nn=input('enter number of cycles (nn): ');
disp(' ATTENTION: Interspaced components should be entered')
disp(' between apostrophes as single string of characters');
disp(' ');
disp('          press any key to continue') ; pause;

% 2. START
for n=1:nn, if (S==1)&(n==1), sw=1; W=zeros(sw, 16,8);
            NAMES=['!']; WW=zeros(sw,sw);NM=[ ];

```

```

end

% 3. INPUT
I=input('enter components ');

% 4. CONVERT INPUT into PIN;
PIN=zeros(8,8); word=[];jj=1; I=[I, '']; ab=abs(I); lab=length(ab);
for i=1:lab, if (ab(i))~=32, word=[word,ab(i)]; else
lw=length(word); PIN(jj,1:lw)=word; word=[]; jj=jj+1; end, end
% 5. CHECKING novelty of PIN against WORLD
old=0; wiold=0; comp=[]; % PIN presumed new

for wi=1:sw %wi: length of World
% 5.1 CUTTING FLAT SLICE OF WORLD W(wi,,:)
fW=zeros(16,8); fW(:,:)=W(wi,,:);

% 5.2 COMPARE flat W and PIN as ordered sets %
eqid=isequal(fW(9:16,:),PIN); if eqid==1, old=1; %PIN is OLD
disp('This is old '),disp(NAMES((wi,:),:)), % wiold=wi; list=find(WW(:,wiold));
leli=length(list); SN=[];for k=1:leli, SN=strvcat(SN,NAMES((leli,:)));end
end,

% 5.3 COMPARE flat W and PIN as sets
set=0;

if isempty(setxor(fW((1:8),:),PIN,'rows')),if old==0,
if eqid~=1,
note = ['Looks like W' ,int2str(wi),': ', NAMES(wi,:)];
disp(note); set=1; end, end,old=1; end
%%%%%%%%%%
if set==1,
nnew=input(' Is it new? 1/0 ');
if nnew==1,old=0; end, end
%%%%%%%%%%
% 5.4. CHECK for SET MEMBERS to create SPECTRUM;
eqcomp = intersect(PIN,fW,'rows');
h=size(eqcomp,1) ; test=zeros(1,8);
for hh=1:h,
if ((~isempty(eqcomp))&(~isequal(eqcomp(hh,:),test))),
comp=[comp,wi];end, end
end %for wi=1:sw
spectrum=unique(comp);les=length(spectrum);
%disp('spectrum: '); %for r=1:les, disp(NAMES(spectrum(r,:))); end
%if old==1,SNU=unique(SN,'rows');disp('OLD spectrum '),disp(SNU),end,
% 6. IF NEW, EXPAND THE WORLD:
% 6.1. NAME THE NEW ENTRY

```

```

if old==0, NAME=input('This is new. Name it ');
    NAMES=strvcat(NAMES, NAME);
% 6.2. CREATE NewPIN containing NAME
NAME=[NAME, '']; NewPIN=zeros(8,8); word=[]; jj=1; ab=abs(NAME);
lab=length(ab); for i=1:lab, if (ab(i)~=32), word=[word,ab(i)];else
    lw=length(word); NewPIN(jj,1:lw)=word; word=[]; jj=jj+1; end,
    end

% 6.3.ADD PIN and NewPIN to WORLD

sw=sw+1; WW(sw,:)=0; WW(:,sw)=0;% PLACE IN THE WORLD

W(sw,9:16,:)=NewPIN(:,:); W(sw,1:8,:)=PIN(:,:);
    % All 16 lines in WORLD are filled up

% 6.4. RECORD NEW LINKS
for ll=1:les, if ~isempty(spectrum(ll)),
    WW(sw,spectrum(ll))=1; WW(spectrum(ll),sw)=1;end, end,

end % if old==0,

%To read an entry from W(x,y,:) %D=nonzeros(W(x,y,:)); D=D'; setstr(D);

end % for n=1:nn
NM=NAMES; world=WW;
disp('If you want to check WORLD for a name, type: link ')
disp('To see NAMES, type: NM ');
disp('To display the 3D world, type plotW ');

```

sct.m

```

% PROGRAM SCALE, script sc; RELATED: link; space lin.mat
% 1. INITIALIZE
S=input('1 to start, 2 to continue ');nn=input('nn ');

% 2. START
for n=1:nn, if (S==1)&(n==1), sw=1; W=zeros(sw, 16,8);
    NAMES=['!']; WW=zeros(sw,sw);
    end

% 3. INPUT
I=input('type interspaced components as single character string ');

% 4. CONVERT INPUT into PIN;
PIN=zeros(8,8); word=[]; jj=1; I=[I, '']; ab=abs(I); lab=length(ab);

```

```

for i=1:lab, if (ab(i)~=32, word=[word,ab(i)]; else
lw=length(word); PIN(jj,1:lw)=word; word=[]; jj=jj+1; end, end
% 5. CHECKING novelty of PIN against WORLD
old=0; wiold=0; comp=[]; % PIN presumed new

for wi=1:sw %wi: length of World
% 5.1 CUTTING FLAT SLICE OF WORLD W(wi,,:)
fW=zeros(16,8); fW(:,:)=W(wi,,:);

% 5.2 COMPARE flat W and PIN as ordered sets %
eqid=isequal(fW(9:16,:),PIN); if eqid==1, old=1; %PIN is OLD
disp('This is old '),disp(NAMES((wi,:),:)), % wiold=wi; list=find(WW(:,wiold));
leli=length(list); SN=[];for k=1:leli, SN=strvcat(SN,NAMES((leli,:),:));end
end,

% 5.3 COMPARE flat W and PIN as sets
set=0;

if isempty(setxor(fW((1:8),:),PIN,'rows')),if old==0,
if eqid~=1,
note = ['Looks like W' ,int2str(wi),': ', NAMES(wi,:)];
disp(note); set=1; end, end,old=1; end
%%%%%%%%%%
if set==1,
nnew=input(' Is it new? 1/0 ');
if nnew==1,old=0; end, end
%%%%%%%%%%
% 5.4. CHECK for SET MEMBERS to create SPECTRUM;
eqcomp = intersect(PIN,fW,'rows');
h=size(eqcomp,1) ; test=zeros(1,8);
for hh=1:h,
if ((~isempty(eqcomp))&(~isequal(eqcomp(hh,:),test))),
comp=[comp,wi];end, end
end %for wi=1:sw
spectrum=unique(comp);les=length(spectrum);
%disp('spectrum: '); %for r=1:les, disp(NAMES(spectrum(r,:),:)); end
%if old==1,SNU=unique(SN,'rows');disp('OLD spectrum '),disp(SNU),end,
% 6. IF NEW, EXPAND THE WORLD:
% 6.1. NAME THE NEW ENTRY

if old==0, NAME=input('This is new. Name it ');
NAMES=strvcat(NAMES, NAME);
% 6.2. CREATE NewPIN containing NAME
NAME=[NAME,' ']; NewPIN=zeros(8,8);word=[];jj=1; ab=abs(NAME);
lab=length(ab); for i=1:lab, if (ab(i)~=32, word=[word,ab(i)];else
lw=length(word); NewPIN(jj,1:lw)=word; word=[];jj=jj+1; end,

```

```

end

% 6.3.ADD PIN and NewPIN to WORLD

sw=sw+1; WW(sw,:)=0; WW(:,sw)=0;% PLACE IN THE WORLD

W(sw,9:16,:)=NewPIN(:,:); W(sw,1:8,:)=PIN(:,:);
    % All 16 lines in WORLD are filled up

% 6.4. RECORD NEW LINKS
for ll=1:les, if ~isempty(spectrum(ll)),
WW(sw,spectrum(ll))=1; WW(spectrum(ll),sw)=1;end, end,

end % if old==0,

%To read an entry from W(x,y,:) %D=nonzeros(W(x,y,:)); D=D'; setstr(D);

end % for n=1:nn
NAMES; world=WW;
disp('If you want to check WORLD for a name, type: link ')
disp('To see NAMES, type: NM ');
disp('To display the 3D world, type plotW ');

```

flatW.m

```

%script flatW
cla
om=length(WW);
PX=zeros(om,1);PY=zeros(om,1);XYP=zeros(om,2);
angles=(2*pi./100).*[0:100];
plot(cos(angles),sin(angles))
hold on
angles=(2*pi/om).*[0:om-1];
for j=1:om
    %plot(cos(angles(j)).*[1 1.5],sin(angles(j)).*[1 1.5])
    text(cos(angles(j)),sin(angles(j)),[num2str(j),' ',NAMES(j,:)])
PX(j)=cos(angles(j));PY(j)=sin(angles(j)); end
XYP(:,1)=PX; XYP(:,2)=PY; gplot(WW,XYP);
%end of script flatW

```

link.m


```
% CHECKING THE WORLD FOR NAME; SCRIPT: link
I=input('NAME to check ');
CI=cellstr(I);
SC=nonzeros(strmatch(CI,NAMES));%find NAME's numbers
LINKS=find(WW(:,SC)); links=LINKS';
LL= [];%list of links
NAMELIST=[];
for i=1:length(SC)
    LL= [LL,(find(WW(:,SC(i))))'];
end

lel=length(LL); for r=1:lel, NAM=(NAMES(LL(r,:),:));
NAMELIST=strvcat(NAMELIST,NAM);end,
NAMELIST=unique(NAMELIST,'rows'); disp(NAMELIST)
```

plotW.m

```
%script: plotW, plot world
close;
om=length(WW);
PX=zeros(om,1);PY=zeros(om,1); XYP=zeros(om,3); PZ=[1:om]; PZ=PZ'/om;
angles=(2*pi/om).*[0:om-1];
for j=1:om
    PX(j)=cos(angles(j));PY(j)=sin(angles(j));
end
XYP(:,1)=PX; XYP(:,2)=PY; XYP(:,3)=PZ;

[iW,jW]=find(WW);
liW=length(iW);
MW=zeros(liW,2);
MW(:,1)=iW; MW(:,2)=jW;
for i=1:liW
    line([XYP(MW(i,1),1),XYP(MW(i,2),1)],...
        [XYP(MW(i,1),2),XYP(MW(i,2),2)],...
        [XYP(MW(i,1),3),XYP(MW(i,2),3)]);
end
hold on,
stack
```

stack.m

```
%script: stack
ZZ=zeros(1,41);
tt=0;
```

```
for zz=0:0.1:1
t = 0:pi/20:(2*pi); ZZ(1,:)=zz; tt=ZZ;
    plot3(sin(t),cos(t),tt),hold on,
    grid on
    axis square
tt=tt+1;
end
```

=====.

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TRANSITION STATE IN PATTERNS OF HISTORY

Yuri Tarnopolsky

ABSTRACT

A review of literature shows that a diaspora of natural scientists interested in history has been forming for some time around the legacy of Rashevsky, Richardson, and Tilly. Analytical history of Bertrand Roehmer and Tony Syme, as well as the study of patterns of military conflicts by Peter Brecke, have a potential of becoming centers of the “naturalization” of historical research.

The existing formal approaches to complex systems create a conundrum of the use of closed mathematical structures for representing open irreversible systems. Pattern Theory (Ulf Grenander) is suggested as another entry in the inventory of methods in this area.

Pattern Theory, with its atomistic realism and preservation of semantics, is uniquely positioned for developing a general representation of Very Complex Open Systems, such as life, mind, and society. The focus of the application of Pattern Theory to history is transition state characterized by its irregularity and, therefore, instability.

A possibility to treat a segment of history as a quasi-chemical structural transformation through alternating stable and irregular states is illustrated on the example of the expedition of Darius against the Scyths.

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1. Preamble

The divide between the two cultures—sciences and humanities—appears to be slowly closing due to two trends. One is the influence of the pervasive science and technology on the creative process in humanities. An installation of the artist Janine Antoni who weaves a recorded pattern of her own Rapid Eye Movements on a traditional loom is an example. The other trend is the unstoppable spread of sciences, enhanced by mathematics and computers, over the traditional areas of humanities. Social sciences seem to be an emerging Isthmus of Panama between the two previously separated continents. Compare three quotations, one of a sociologist, the second of a physicist, and the third of a fiction writer.

I should like to deal with the promise of social science in terms of three prospects which seem to me both possible and desirable for the twenty-first century: the epistemological reunification of the so-called two cultures, that of science and the humanities; the organizational reunification and redivision of the social sciences; and the assumption by social science of centrality in the world of

knowledge (Wallerstein, 1998).

Today we are becoming more and more conscious of the fact that on all levels, from elementary particles to cosmology, randomness and irreversibility play an ever-increasing role. Science is rediscovering time. This obviously introduces a new dimension into the old problem of the two cultures, science and the humanities (Prigogine, 1983) .

But Denise left the kitchen and took the plate to Alfred, for whom the problem of existence was this: that, in manner of a wheat seedling thrusting itself up out of the earth, the world moved forward in time by adding cell after cell to its leading edge, piling moment on moment, and to grasp the world even in its freshest, youngest moment provided no guarantee that you'd be able to grasp it again a moment later (Franzen, 2001, p. 66).

In the same book Jonathan Franzen uses adjective “Cherenkov blue,” comparing an eye color to a physical effect that can be observed only in some nuclear reactors.

The above excerpts shall usher us into the area that has been attracting attention of philosophers since times immemorial and physicists, mathematicians, and computer scientists for decades: history. What can hard sciences say about human history? This time it is a take of a chemist.

In his *The Rise and Fall of the Great Powers* Paul Kennedy (1987) discussed the reasons why no great power in the last 500 years of history was able to maintain its status. Neither was any great empire of the earlier times, although at the peak of power the decline seemed for most observers unthinkable. In his subsequent book Kennedy (1993) reiterated and emphasized numerous tensions that could threaten the current American status.

Kennedy's earlier book was written in before the collapse of the USSR and the later one before the war on terrorism and the rise of anti-Americanism. Nevertheless the aforementioned conclusion about the transient character of economic power and military domination seems to be a *regularity* of history. If history comes as a surprise, then one day we might be surprised by a great power, remaining indefinitely unchallenged, as if history ended its regular course, in accordance with Francis Fukuyama's (1992) conclusions. If history had the invariance analyzed by Kennedy and obvious from any textbook of history, the *pattern* of the rise and decline would persist. The problem with this reasoning is that we have no means to supply any facts whether in support or in refutation because they reside in the future. In the absence of facts, a theory is a substitute, but there is no such universally accepted theory.

In spite of an accumulated library of patterns, warning signs, and wise predictions, history always surprises the contemporaries, requiring a *post factum* explanation. The main reason for this Cassandra Effect is the impossibility to tell **when** the next turn comes.

Paul Kennedy, emphasizing the difficulty of predicting the future, presented a series of arguments pro and contra the thesis that USA was entering a period of decline as a great power. The question is: what is the relation between the regularity and surprise in history? What is regularity (law, invariance), surprise (irregularity, novelty, invention), and what is a rationale for a particular timing of a historical event?

It may be too early to expect satisfying answers to these questions, but it might be the right time to ask in what direction should we look for them.

2. The intent of the paper

It would be possible to discuss the above example in search for a consensus if there were some theoretical foundations of history. At a certain level of abstraction, the theory would be invariant regarding a substitution of Roman Empire for USA or the second Gulf War for the war of Persian king Darius the Great with the Scyths. No historian, however, would sacrifice the obvious differences.

If we remove the terms (semantics) from consideration, what remains is relations (syntax), which is all that most mathematics is about. A search for such foundations by means of natural sciences, which unlike humanities are based on consensus rather than on institutionalized dissent (compare with dissent-based philosophy, Collins, 1998), has its own history in the context of the study of *complex systems*. They will be further abbreviated as LMS—life, mind, and society—in order to avoid the difficult problem of defining complexity where no consensus exists.

The purpose of this paper is to informally present Pattern Theory (Grenander, 1978-2003) as a possible component in scientific study of LMS and history in particular. I am not a mathematician to whose natural habitat Pattern Theory would belong but a chemist who intuitively perceives it as a kind of meta-chemistry, i.e., theory of atomistic structures.

My first suspicion that chemistry is a kind of a metaphor for history goes back to the 1970s, when I, together with many intellectuals in the former USSR, saw the Communist system as self-destructible and doomed to collapse. The question that nobody could answer—as nobody can answer the questions about current great and small powers—was: **when**? Today practically all professionals in the field of history and political science express their *surprise* that it came so *soon*. For about a decade after 1917, when the Bolsheviks came to power, the observers were *surprised* that it had lasted so *long*.

Chemistry studies events in systems with extremely high and incompressible complexity. It possesses some uncommon tools to answer questions pertaining both to the nature of possible events and their **timing**. A chemist sees time through bifocal glasses: one lens for long distance in time and another for a close-up. Remarkably, it reminds the vision of a historian of the French *Annales* school, which distinguishes between *la longue duree* (Braudel, 1992) and the short run of smaller scale *events*. This type of historian regards the totality of all factors, such as economics, geography, beliefs, etc., and pays attention to numbers.

The outcome of a chemical transformation *in the long run* is not the same as observed with a stopwatch. The former inexorably goes toward equilibrium, while the latter is the result of the **fastest** among concurrent transformations. Catalysis can selectively speed up some transformations. By using the entirely catalytic and therefore fast biochemistry, the living organism escapes equilibrium but pays for that by the absence of anything comparable with the historical *longue duree*: the “great power” of an individual organism always collapses.

Bertalanffy (1968) defined *system* as a set of units with relationships between them, which is the same as to say that a “systemic” system can be mapped on a mathematical system. An important novelty was Bertalanffy’s emphasis on open systems and steady states instead of equilibrium.

Mathematical systems and structures, however, operate under the axiom of closure, which is sometimes regarded as part of the definition of operation. Although renormalization can change the base set in an orderly manner, the new set is closed, too. I am not aware of any inquest into the possibility of describing an open system in terms of a strictly formalized and closed one. The concept of an open *system* represented by a closed one, however, is just one possible liability of the traditional systemic approach. The other one, not too often discussed,

encumbers the very term *theory*. What is theory? There are theories of philosophical grandeur, aspiring the ultimate generality, and there are working theories seeking empirical practicality and subject to experiment.

The additional purpose of this paper follows from my belief that a scientific *theory* of the second type, as it is most widely understood, has to satisfy a criterion of *realism*, i.e., being *recognizable* by an empiricist as relevant for the appropriate domain of a particular hands-on science. Thus, any meta-chemical construct should conform to a chemist's view of chemical phenomena and any meta-theory of history should not be so elevated above the daily craft of historians that the names of persons and circumstances of events would be obliterated by symbolic formalism. In other words, the theory has to fill up the space between the roof gardens of abstract theory and the basement storage of the facts. The contraposition of theory and practice is sometimes expressed in terms of a fissure between syntax and semantics.

This paper borrows important ideas from the manuscript *History as Points and Lines* by the author and Ulf Grenander. The entire project of pattern history was initiated by Ulf Grenander in 1994 and most important ideas belong to him. My own contribution is limited to the chemical angle of view, use of the concept of transition state, and the idea of an open (Heraclitean) formal system, in contrast to the closed (Aristotelian) system (Tarnopolsky, 2003).

The following short and selective *historical* overview is intended to help illuminate the search for mathematics of history as well as the epistemic place of Pattern Theory in among other approaches.

3. Historical sketch

Leo Tolstoy filled up the volumes of his *War and Peace* with hundreds of names, situations, and events, recreating the atmosphere of a society in the process of a historical transformation from peace to war and back. He did it in terms of observables: name, facial expression, movement, utterance, location, thought, etc. He concluded his epic with a chapter of a contrasting nature where he outlined his theory of history, using images and metaphors of calculus and chemistry to present history and war as what we would call now a dynamical system of statistical physics. It

could well be described by differential equations as well as intensive (will to fight) and extensive (army size) parameters. On Tolstoy's mathematics, see Vitányi .

After Leo Tolstoy, one of the most recent—and gripping—attempts of humanities to paint a historical picture with colors borrowed from sciences belongs to philosopher **Manuel De Landa** (1997), who, for example, unites the origin of minerals, emergence of skeletons in biological evolution, and the rise of the cities under the same metaphor of mineralization. The close relation between metaphor and what is intuitively understood by the term *pattern* is palpable. This line leads back to **Michel Foucault** (1970) whose thinking was clearly mathematical but the language metaphoric and artistic. On metaphor in historiography—and the complex picture of the modern philosophy of history—see Ankersmit (1994).

In 1968, one hundred years after *War and Peace*, **Nicolas Rashevsky** published his *Looking at History through Mathematics* (Rashevsky, 1968). He defined the purpose of his book as a collection of illustrations “how mathematical reasoning *could in principle* be used in attempted explanations of *some* historical phenomena.” Among them, imitative behavior and the development of aggressiveness, beliefs and prejudices, effect of the shoreline on cultural development, role of individual (**without mentioning** Leo Tolstoy), and some other aspects of “long history.” In his earlier “*Mathematical Biology of Social Behavior*” (Rashevsky, 1959), mathematics of history was a topic of an appendix, with such subjects as mathematics of political freedom.

In modern terms, what Rashevsky applied to history could be called population dynamics started by Lotka (1956|1925) and Volterra (1931), who were inspired, by the way, by chemical kinetics. Rashevsky focused on the populations of *memes*, although Richard Dawkins (1989), who invented the term, **did not mention** Rashevsky in his book. For example, “militarism” and “pacifism,” “laziness” and “activity,” are competing pairs of behavior reinforced by mutual imitation, i.e., replication, and inhibition for the sake of consistency of mentality. The main mathematical apparatus applied—and employed also in chemistry and artificial life—is differential equations.

Rashevsky gradually became dissatisfied with the fragmentary descriptions of various aspects of LMS, including his own contributions. He came to the conclusion that physics in metric space may give a lot of details about life but not the entire view of the living system. He

formulated a cardinally different idea of “relational” biology and sociology as an opposite of the “metric” and fragmentary physical view of the complex systems. For Rashevsky, therefore, the term “mathematics” in applications to LMS has two meanings: (1) the down-to-earth calculations along a *physical* model developing as a time series of states and (2) the *geometrical* (in Felix Klein’s sense) view of the system. He believed that the two should better be “objects of parallel studies.”

As an example, a whole array of real structures, from the movement of a bird to composing a love sonnet can be mapped on a directional graph of realtions. He specified the edge of such a graph as “immediate precedence” or “immediate causation.” Similarly, the movement of a paramecia toward food is a relation, which is fully preserved in humans, in spite if the evolutionary gap. Rashevsky stated that a complex (*i.e.*, LMS) system should be described in terms of *patterns* defined as families of bijective mappings of one system on another (homeomorphisms). In his *Mathematical Biophysics* , Rashevsky saw “the organism as a set of mappings, categories, and equivalences.” (Rashevsky, 1960, Vol.2, p. 390).

Rashevsky’s abstract ideas were further developed by his student **Robert Rosen** (1985-2000) whose major interests comprised general theory of natural systems, including LMS. In particular, Rosen was interested in anticipatory systems **where the change of state depends on future circumstances**, which returns us to the starter example. For such systems a model is a must. It was the interaction through an interface between the natural system and model system where the solution of the problem of anticipation was expected. Rosen looked at the coding through the interface between the abstract model and its real source as a creative act, stating that the coding did not belong to the system and its model.

The mathematical structure he and Rashevsky used was category theory (Mac Lane (1971), Rosen, 1985-2). Category is a generalized monoid on a set of *objects*. The objects of category theory can be various mathematical functions and structures. Monoid is a category with one object and semigroup is monoid without identity. What unites all these compositional structures is associativity and the absence of the axiom of inverse, which alone **does not mandate irreversibility**, however.

Rosen expected a complex system to be unpredictable, surprising, faulty up to a point, and exhibiting novelties. He, however, showed no affinity for thermodynamics of Ilya Prigogine who concentrated exactly on the surprise in the behavior of natural systems, but widely used *realistic* physical and chemical models.

Both Rashevsky and Rosen, following Bertalanffy, understood theory as a mathematical structure with irrelevant semantics, self-contained and self-explanatory, which, probably, worked to fence off the curiosity of empiric scientists.

A. C. Ehresmann (mathematician) and **J.P. Vanbremeersch** (physician; 1987, 1991, 1999), developing Rosen's ideas, came to the conclusion that natural complex systems "cannot be studied using observables defined on a fixed space of phases and following uniform laws" (1999). In their theory based on category theory, the set of elements in the *universe* is updated from state to state. It does it by "absorbing" some external elements and "suppressing" others. The efficient cause of an operation is a module called coregulator (CR), which seems to be an analogue of the enzyme in Gerhard Mack's universal dynamics, see below.

It is possible to formally remain under the axiom of closure because the system consist of a hierarchy of levels of complexity. The trade-off is the high complexity of the theory itself that has to trace all changes, ultimately, in terms of atoms. The theory, therefore, is, actually a representation of total available knowledge. The theory requires an *internal memory*. This requirement, in my opinion, is partly satisfied only in the case of the mind. Neither biosphere nor society do not have (yet) a centralized memory. As far as human history is concerned, only historians—but not the agents in AI sense—are in collective possession of such memory.

To compare with Pattern Theory (Section 6), pattern, according to Ehresmann, A.C. and Vanbremeersch J.P. (1999) is:

A pattern in a category K is the data of a graph I and a homomorphism P from I to K .

Graph I here is the graph of arrows, i.e., associative morphisms interpreted as causal relations.

The statistical study of wars and conflict risk estimate by **Lewis F. Richardson** (1960-1993), whose studies of shorelines is said to inspire Benoit Mandelbrot's fractals, is closer in its scope to the early works of Nicolas Rashevsky.

Among Richardson's predecessors in quantitative history was **Pitirim Sorokin** (1937), a remarkable American sociologist and author of the multi-volume *Social and Cultural Dynamics*, whose life path once crossed with that of Lenin. The audacious step of Sorokin was to quantify a repeating historical *pattern* (such as war, revolt, etc.) not only in terms of *extensive* frequency but also *intensive* scale. This alone creates preconditions for hard science.

Richardson, whose main works were published posthumously, left a fruitful and lasting heritage, named after him research institutions, his works collected and re-published. His effort on collecting databases is continued on a large scale by **Peter Brecke** (Long, 2003) who is in charge of the project pursuing taxonomy of violent conflicts and identification of warning signs of conflicts **by methods of pattern recognition** at Sam Nunn School of International Affairs, Georgia Institute of Technology. This project might finally abate the historically well founded pessimism about the ability of humankind to draw lessons from its history. Clio has now a balance sheet. Notes on the methods of quantification of security are on the Web (Brecke, 2002). About the entire project, see Brecke (WWW).

There is an impressive literature on *Nonlinearity, Complexity, Combat & War* (War, WWW).

Among Richardson's results was the conclusion that military conflicts follow Poisson distribution. To generalize, historical events are rare and too many of them at the same time are improbable. This resonates well with the chemical paradigm where one or two, rarely three molecules are involved into a "chemical event." Both history and chemistry are local.

History, philosophy, and art—the realm of semantics—have been among life long interests of **Ilya Prigogine**, a Renaissance man and the founder of non-equilibrium thermodynamics and, arguably, the entire modern science of complexity. He repeatedly approached the problem of human history in view of the behavior of the complex non-equilibrium systems he was the first to study hands-on (Nicolis and Prigogine, 1989, Prigogine and Stengers, 1984). He has been especially interested in the problem of time and its

irreversibility in history, in contrast with classical physics and contrary to the Einstein's dictum "For us believing physicists, the distinction between past, present, and future is only an illusion, however persistent." (Einstein-Besso, 1972).

Prigogine's view of history has two major components:

1. Prigogine united many natural systems, which develop complexity and order, under the notion of dissipative structures. The eddies in a fast flowing liquid is an example. If there is a constant supply of work and its dissipation in the form of heat, the flow of energy keeps the system far from equilibrium and maintains order. A dissipative system can switch to different modes and manifest a coherence and order impossible at equilibrium. He suggested that life and society may belong to this class of systems.

2. Prigogine suggested that the irreversibility of historical time is a consequence of the series of bifurcations and symmetry breaking in the evolution of dissipative structures. According to Prigogine, it is the sequence of random choices that makes history irreversible. In terms of dynamical systems, it means that the phase trajectories of a dissipative system are diverging: such system does not possess Lyapunov stability. Prigogine compared its behavior with kneading the dough (baker's transformation). Slightly modifying his example, two raisins put in the dough side by side, will most probably diverge during the kneading. Note that the concept of stability of dynamic systems does not even involve thermodynamics with its energy, entropy, and temperature that need to be defined on social systems.

Prigogine has not applied his theory to history in any systematic way, yet some far-reaching conclusions follow. The dissipative system stays far from equilibrium **while the dissipation of energy lasts**. When it comes to an end or the system itself breaks down, it returns to an equilibrium or stays very close to it. Therefore, an LMS system, for example, an industrial civilization, cannot maintain its structure if either the supply of energy comes to an end or, which is sometimes overlooked, the dissipation becomes hindered because of the rising ambient temperature. The only alternative is a deep restructuring of the system. Dissipative system, as any thermal machine, is positioned between supply of work (order) and disposal of heat (chaos).

All such reasoning, however, as any doomsday scenario, is of little immediate concern for most people because the internal time of non-equilibrium thermodynamics is not in any way connected to the calendar time. The present pattern of industrial civilization emerged after 1700,

when mineral energy had become involved into the process of dissipation by technology.

Nobody knows when the global baker will apply his hands next time, but thermodynamics warns us where to look for possible trouble. It suggests a gauge for vital signs of a civilization jammed between mineral fuel and atmospheric temperature.

The concept of relational theory, with direct references to Rosen and further back to Rashevsky and, in most recent publications, to Ehresmann and Vanbreemersch, but **without mentioning** Pattern Theory, was expanded to a *universal dynamics theory* by physicist **Gerhard Mack** (1995 - 2001) who is looking for a “a universal chemistry in which general objects and links substitute for atoms and their chemical bonds,” starting with a “preaxiom: The human mind thinks about relations between things or agents.” The inception of the project was influenced by philosophy and Wittgenstein in particular. The further development of this project is planned to take a form of computation.

Mack’s universal dynamics is relevant for the topic of history for two reasons. First, it covers not just a system but also a *history* of a system, which is itself a system called *drama*. Second, it advances a very fundamental idea of locality (first implemented by Maxwell’s dynamics instead of Newton’s action at a distance) in the following axiom where *arrow* is a term for morphism in category theory:

4. locality: Some of the arrows are declared direct (or fundamental); they are called links. All arrows f can be made from links by composition and adjunction, $f = b_n \circ \dots \circ b_1$; ($n > 0$) where b_i are links or adjoints [reversed arrows] of links; the empty product ($n = 0$) represents the identity. (Mack, 2001)

The elementary act of change in the system, therefore, happens only in the **topological 1-neighborhood** of an object, where a composite link is made fundamental or a fundamental link is made virtual. When the last fundamental link is gone, the object dies.

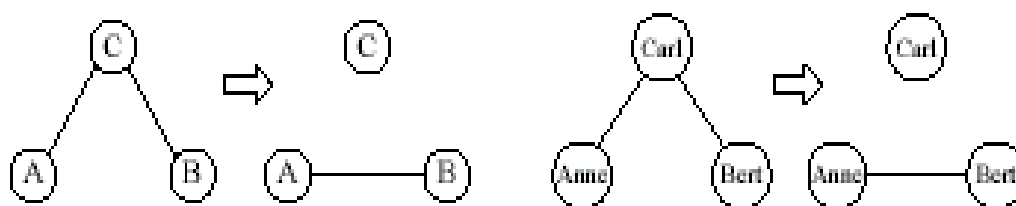


Figure 1: “Catalysis in chemistry and elsewhere. A catalyst C binds molecules A and B. First a substrate-enzyme complex is built, where A and B bind to C. Next the composite arrow from A to B becomes fundamental” (the Figure and caption are from Mack, 2001).

The atoms of a minimal change of the system are transformations of the graph of relations in the 1-neighborhood of a node: the edge can be either eliminated or established and the node can be duplicated. Mack distinguishes between the following four transformations, of which the first is the atomic one.

1. motion: “promoting” a composite arrow to the status of a direct one, i.e. link;
2. growth: by making a copy through a series of motions and duplications of nodes;
3. death: the only irreversible transformation, consisting of removing all the links;
4. cognition: approximately can be described as recognition; it establishes links between two non-atomic objects, which are, typically, isomorphic; cognition creates new arrows.

The closest to cognition phenomenon is enzyme-substrate interaction. The idea of the move is illustrated by Gerhard Mack with the example of generalized catalysis, Figure 1.

In universal dynamics the local transformation is performed by *enzyme*. It is not exactly what catalysis means in chemistry, but rather what *command* means in programming and *coregulator* in the system of Ehresmann and Vanbreemersch (1999): the efficient cause of a local change in the state of the system, i.e., a demon of a kind.

On the surface, the system under universal dynamics looks like a transformation of a connected graph that preserves its connectedness and occurs as a sequence of atomic changes one edge at a time. I do not see, however, how any new object can appear in the *drama* (which

can be stochastic) and the notion of novelty does not surface in a mathematical structure under closure.

The question that arises when a compositional mathematical structures without a unique inverse is applied to a real system is: what if two causation arrows contradict each other? A similar question: what if two diverging arrows cause incompatible events? These questions do not apply to always “self-consistent” physical systems but are typical for LMS. I do not know the answers, although Ehresmann and Vanbremeersch (1999) allow in principle such contradiction of arrows.

For details one should better look into the sources. This project goes far beyond the initial relational concept of Rashevsky and Rosen and touches upon the deepest foundations of sciences. It has been evolving and some aspects lack details while others, such as theoretical physics, are beyond my competence.

A small set of minimal transformations can be found also in the relatively recent “Evolving Algebras” of **Yuri Gurevich** (1995) where the *arity* (number of arguments) of the transition function can be >1 . Convergent or divergent incompatible outcomes would make computation impossible, but in political life, the right hand often does not know what the left hand is doing.

The idea of 16 *archetypal morphologies*, i.e., basic transformations of realistic structures, among them—adding or removing an edge or a node of a graph—goes back to **René Thom** (1973) who saw it as beginning, ending, fastening and cutting. Thom’s ideas, unjustly trampled, (as Thom believed, because they did not deliver a quantitative prediction), may be a key to the radical simplification of social complexity. Thom’s *stirring*, which looks as a bell-shaped curve, can be identified with the transition state (see Section 6). the concept of catastrophe itself is what happens between the initial and final states.

From the chemical perspective, a set of two operations is sufficient to build a structure: form and delete a bond. In Pattern Theory (see the corresponding section), a node (generator) can be added and deleted. The confusing abovementioned situations in both chemistry and Pattern Theory are *irregular*, but natural: irregularity is just a degree of regularity, like chaos is a degree of order an *vice versa*.

Artificial intelligence used to ignore individual history or *story* (Schank and Abelson, 1995) of a robot or computer. The role and possible use of story in complex systems has been insightfully analyzed by **Chrystopher Nehaniv** and **Kerstin Dauterhahn** (Nehaniv 1998-1 and -2) and summarized as: “Being alive means having a lifetime, without a reset button.” (Nehaniv and Dauterhahn, 1998-2) Nehaniv *et al* connected *story* (ontogenesis in biology) with the thermodynamic irreversibility of life and assigned to semigroups the label of “algebras of time.” Nehaniv *et al* formalized the unique direction of ordering in semigroups and included “pools of reversibility” into the general semigroup structure that does not require irreversibility axiomatically. Nehaniv and Dauterhahn (1998-2) explicitly stated the problem of the limits that a closed mathematical structure imposes on the realism of representation but pointed to a “dynamically changing” what the system considers as its inputs and which are relevant as a possible direction of solving the problem.

Thermodynamics, which establishes a preferred direction of time, can hardly be classified as either syntax or semantics. It is external to timeless mathematical structures and finds no place there. The relation theories expurgate metrics together with semantics and find no place for thermodynamics. An intriguing case of thermodynamics on a formal but tainted with realism system is *reversible computation*, **Rolf Landauer** (1961), **Charles H. Bennett** (1973). It arose from the problem of heat generation by the computers that have to erase all intermediate data and clear the registers after each computation and therefore, dissipate heat without creating information. See also Section 6 in Bremermann (1974).

The information produced during the individual *history* of a finite state automaton, such as, for example, Turing machine, is discarded or, more generally, the mapping of a state back onto the previous state of a computation cycle is not bijective

The problem “how to save energy”, therefore, resonates with “how to remember the lesson of history and survive the next election,” in political language, as an alternative to starting the second campaign from scratch.

The reversible computing works on a **new** task by

1. **saving** all intermediate results,
2. generating the output,

3. retracing the computation back to the input, which is possible because of the saved history of the computation, while reversibly erasing only the history. While reversing the computation, a Turing machine that represents the finite automaton has to change the **read-shift-write** quintuple

$$\langle AT \rightarrow T' \sigma A' \rangle$$

where A, A' refer to states, T, T' to the tape, and σ is the movement of the head to the **write-shift-read** quintuple.

The overall result is the decrease in the dissipation of energy, which is still higher than in the direct computation alone but less than in the entire cycle of irreversible computation.

Motivated by the goal of bridging the gap between history and sociology. **Bertrand M. Roehner** (physicist) and **Tony Syme** (economist and sociologist) formulate their subject in *Pattern and Repertoire in History as analytical history* (Roehner, 2002). In their most innovative, wide in scope, and rich of facts work they follow the agenda of Charles Tilly (1981, 1984) who—very much in line with one of the stimuli that drive chemists and mathematicians—wanted to know whether the repertoire of elementary blocks in history really **existed**. Tilly, the student of Pitirim Sorokin, made clear that the binary relations between the blocks were of the primary interest for a historian-sociologist.

It may seem that, since history as a whole is a unique sequence of events, developing at specific times and locations, it can be only described as a whole but not studied by the scientific method. Natural sciences, since Aristotle and through Descartes, follow the method of analyzing a complex phenomenon and dividing it into simpler units. A closer look at history reveals that it is built of standard modules which repeat across time and space and can be compared and generalized in the form of *patterns*. The perception of wars, revolutions, and reforms as standard blocks of history is by no means new. The authors discover, however, that the smaller building blocks of the large events are also to some extent standard and enclosed in each other in fractal manner. Moreover, the smaller blocks are highly repetitive throughout time and geography.

Roehner and Syme note that real physical processes, like the warming of a cup of cold drink, are by no means simple. Only by splitting them into simpler problems physics managed to successfully explain them. They refer to simplicity as “a basic requirements of the human mind.”

The main methodological idea here is to look for *patterns* or *regularities* in history at a microhistorical level, largely regardless of their macrohistorical environment. The obtained knowledge can be further used for explanations at the macrohistorical level.

To give an example, the apparently unique meetings of the French Estates-General are elements of a larger set that includes also the meetings of the parliaments of German and other European states of similar historical periods, while the French Revolution itself is an element of the set of European revolutions, successful, as well as abortive. The sale of Church property occurred also twice in England and once in Austria at completely different circumstances.

The comparative method, with its long jumps, lies beyond typical historiography, but the description of modules follows the historiographic tradition of a consistent narrative. To completely appreciate the wealth of material, the book must be read in its entirety. Many episodes of world history reviewed in it can hardly be found in general courses. Authors' analysis of difficulties and perspectives, as well as the task of a computerized Very Large Chronicle project is marked with the enthusiastic practicality typical for large scientific projects, although to recall the Manhattan Project would be politically incorrect.

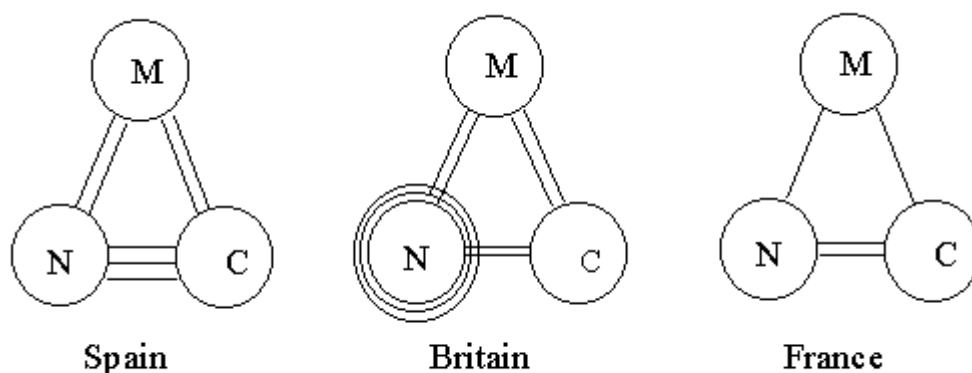


Figure 2. Monarchy, nobility, and clergy in three kingdoms, along Roehner, 2002, Fig. 2.1, p. 76. M = Monarchy, N = Nobility, C = Clergy

organized behavior but its detailed mechanism for any dissipative structure, especially, of a chemical nature. Analytical history provides us with both vocabulary and structural elements from which the historical complexity is built and the authors are looking toward the syntax "grammar" of it all.

To what extent a social structural chemistry can be quantified, the achievements of the fast developing trend of visualizing social networks (**Lothar Krempel**) show. This approach is strongly metrical. A number is associated with both nodes and edges of the graph, and all nodes are labeled with unambiguous semantics.

Two examples will do here.

Figure 3 presents the structure of visits at Duisburg Zoo (Germany). The size of the spheres corresponds to the number of visits and the width of the connecting lines gives the traffic. For example, the largest sphere in the bottom left hand corner is Main Entrance, from which one can go NW to Horses and from them to Kangaroos or NE to Parrots.

Obviously, we deal here with a very general representation. This picture can be *transformed* into an endless variety of configurations filling up a topological space with Hamming metrics. The neighborhood of a configuration includes all configurations with a single changed bond. This closed structure can be opened by expanding the neighborhood to **new** nodes, while their elimination would ensue after removing all links. The Duisburg Zoo must have had its own history in which sections were added, removed, and added again. This history would also reflect changes in traffic and number of visits. If normalized, the numerical values can be expressed as probabilities.

The second illustration, Figure 4, shows two snapshots of the dynamics of automobile trade 1980 and 1994. These configurations are already very close to those of Roehner and Syme.

A stunning variety of visualizations can be found in: Dodge (2001).

To conclude the review, the entire area of structural representation in humanities owes a lot to Claude Lévi-Strauss and structuralism (Lane, 1970). It seems that the initial wave of

structuralism could not sustain itself in the cannibalistically competitive atmosphere of humanities with its generation wars and post-ism waves, but he is unquestionably among the founding fathers of the future consensus.

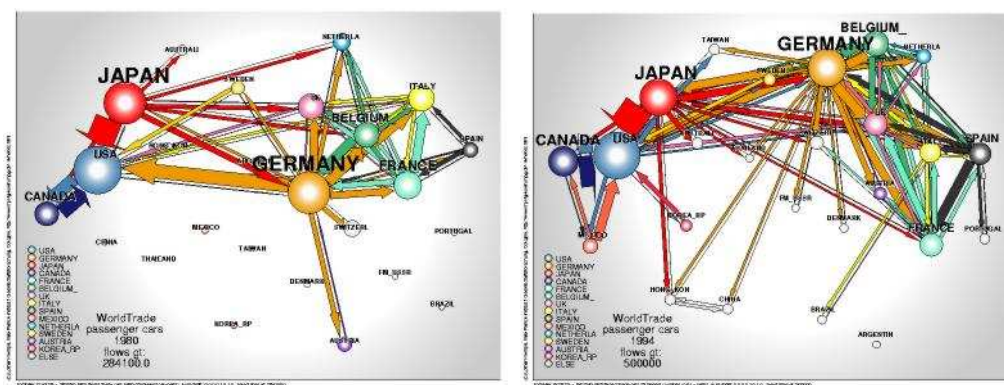


Figure 4. Dynamics of world automobile trade in 1980 (left) and 1994 (right). From Krempel 1. Source <http://www.mpi-fg-koeln.mpg.de/~lk/netvis/global/autochap3.html>

In this review I have left out a large area of mathematical sociology, already sufficiently naturalized. For the entrance to the area, see ASA (WWW). The volume of works in 2-neighborhood (and farther away) of “hard” history is enormous.

4. History and thermodynamics

Neither history, nor thermodynamics, nor, especially, mathematics belong to my professional area. The following is just an informal look from aside, aiming at some distinctive properties of Pattern Theory.

Reversible computing, although turned impractical, opened an entire and still unexplored area of using history for applied problems. Bennett’s paper (1973) is interesting also from another angle. It ends with a comparison of computation with mechanisms of molecular biology such as the template synthesis of messenger RNA and its reversible degradation. Bennett notes

that although this process is also somewhat wasteful, it is much more efficient than irreversible computation. Bennett's description of the role and thermodynamic mechanism of catalysis stands alone with its high chemical accuracy.

What is known about enzymatic action fits well the framework of organic chemistry. Enzymes are proteins folded into a particular shape, which presents a real mystery. They easily solve the problem of their own folding into whimsical but reproducible shapes, which for humans is one of the hardest computational problems requiring brute force. This representational gap—it should not be hard for us what is easy for nature—may mean that it is not the final shape that is coded in their primary structure, but **the reversible history of folding**.

To illustrate the relation between history and thermodynamics, let us invoke again Maxwell's Demon, whose behavior can be mapped on the behavior of a human being. A biologist's argument against Demon can be as follows. Certainly, Demon can perform his job while he is alive. He would need energy, however, to process the visual information, send the efferent signals to his hands, and work against the door spring or, if there is no spring, against the inertia of the door. Therefore, the demon is possible, *modulo* his energy supply. He will have a history with a beginning and the end. This argument—only half-unserious—implies that in order to have a history, a system needs to dissipate energy, whether it consumes it or not. This argument does not even mention entropy.

In a mathematical system, the act of combination of some elements of a set into a subset, as well as any operation and mapping, does not require any energy, which is beyond the concept of mathematical structure. But why? Nothing in the nature of mathematics forbids us to assign metrics to the operation of combination. In reality—physical, chemical, biological, and social—two objects combine because either they have attraction to each other (i.e., the combined state has a lower energy than a separated one) or there is a source of energy to keep them together in spite of their mutual repulsion, or there is a constraint on separation.

Thermodynamics is absent from the syntactic representations of complex systems. Neither does thermodynamics belong to semantics. Thermodynamics follows from the idea that to each binary mathematical operation on the *real* system corresponds a change of some value (energy, free energy, attraction, stress, strain, etc.), which arranges such operations in at least a partially ordered set.

Coming back to the problems with the mathematical structures under closure, noted by Nehaniv and Dauterhahn (1998-2), the situation in a mathematical system is the same as with Prigogine's system where the phase trajectories not only diverge but also converge. The transition functions in a representation of the system **may not** have a single inverse and they form a semigroup, non-restrictive to reversibility. I tend to believe that an open mathematical structure for real systems should include "Prigogine axiom" which—scratching the ear of a mathematician—would sound something like:

There is a distance $d = \Pi$ between the elements of a semigroup expansion (product of all partial histories, i.e., total history without repetitions) such as if $d > \Pi$, the expansion has no inverse.

Irreversibility in LMS does not follow from thermodynamics alone. It follows from an open character of the system in which information is erased and lost. For such a system to exist without essential loss of complexity, an acquisition of new information is necessary.

It is easy to formalize loss, but how to formalize novelty? Transformation is function f on set X :

$$f: X \rightarrow X$$

This leaves no place for either expansion or contraction of set X . Transformation f_o on an open set would mean:

$$f_o: X_t \rightarrow \bigcup (X_{t+1}, \Delta X_{t+1}),$$

where ΔX_{t+1} is a change of the universe of the mathematical system.

To abandon the axiom of closure, however, would mean a profanation of the entire mathematics. Bourbaki, probably, realizing that, ended his *Set Theory* (Bourbaki, 1968) with a strange construct: the set which is the mathematical image of emergence: a combination of elements of the basic set becomes a **new** element in an expanding and partially ordered set: the scale of sets.

In a very general sense, there is an obvious but rather metaphoric relation between gauge theories in physics (Moriyasu, 1983) and any theory invariant **regarding the change of the base set**. It seems that Pattern Theory is the only one developed theory of this kind. Probably, only a very abstract mathematical analysis can answer the question whether the world from physics to poetry is essentially uniform. From the point of view of PT, this is certainly so. Intuitively, it seems that Robert Rosen was right and simple systems are rare exceptions in the curved evolving universe. It is interesting to see Gerhard Mack's progress.

The evolving scale of sets with forgetting and loss of elements, balanced with an inherent expansion is, in my opinion, a basis for an open associative mathematical structure that does not contradict the axiom of closure because the basic set, which for real LMS systems is the alphabet of a language or the elementary percepts (cells of the retina, tactile receptors, etc.), remains constant at least in the medium run. The function of the language is to create a sufficiently large combinatorial space for a limited size of the combination. Taking an average length of a word as 5 letters and alphabet of 25 letters, the abstract word space contains 5^{25} words. Only a tiny part of this space is occupied by existing words, as a tiny part of the display pixel space is occupied by meaningful images. This property of an extremely sparse use of combinatorial space is an intrinsic property of LMS.

Instead of describing LMS in thermodynamic terms as systems far from equilibrium, we can describe them as systems that always occupy only a very small part of all available combinatorial space. Complex systems, therefore, are **simpler** than they could theoretically be.

Although any concept and even a word of the vocabulary has its own history, this history is usually forgotten. For example, the words war, and chemical bond have completely lost their histories, while the word rose is still ties its meaning to some sensory perceptions. In this way, a knowledge representation becomes an open system.

5. Pattern Theory

A mathematical theory that can be recognized by a chemist as meta-chemistry was first introduced in the 1960s, around the same time as “categorical” theory. Pattern Theory of Ulf

Grenander (1976-2003) assigns metrics and structure to the naked operation of composition. It incorporates not only atomism and Klein's geometry (transformational invariance) but also opens the door to thermodynamics. Moreover, it opens to openness itself. To an eye of a chemist, it does it by realistically implementing atomism and the principle of locality.

Constructs of atom-like elements connected in a certain order are the original subject of chemistry, not borrowed from physics. Both chemistry and sociology, as well as a large number of other disciplines, regardless of whether they are of human or inanimate origin, describe objects of various nature and complexity in terms of their structural elements: building blocks and bonds between them. Pattern Theory is the mathematics—and universal chemistry—of such objects.

The papers and books on relational LMS are conspicuously devoid of realistic examples. On the contrary, the first impression one might get from a book on Pattern Theory (Grenander, 1995) is the cornucopia of illustrations as different as skeletons and languages, fairy tales and stomach shapes, mitochondrias and clustering of human settlements, with a potato on the cover and two color plates of battlefield paintings inside.

Pattern Theory, when first introduced, was based on four principles:

(1) **atomism** of building blocks (generators) possessing a selective ability to (2) **combine** with each other according to rules of combination, which leads to regular configurations that are (3) **observable** as images. The fourth principle is (4) **realism**:

A theory of patterns that would not take into account how actual patterns behave would be severely limited in its applications. We must, therefore, assure that the theory is realistic so that it can deal with real patterns (Grenander, 1976, p.3).

This is the kind of realism an empirical scientist would expect from a theory. Let us note that by building blocks Ulf Grenander understood also “abstract symbols, sets, relations, or functions,” which puts it at least at the same level of generality as category theory.

NOTE ON ATOMISM. Atomism is traditionally attributed to Democritus and Lucretius. Regarding the philosophical roots of modern mathematical atomism, it seems unfair to omit Leibniz with his monadology: “

“3. These monads are the true atoms of nature, and, in fact, the elements of things.

.....

8. Whatever is in a composite can come into it only through its simple elements and the monads, if they were without qualities (since they do not differ at all in quantity) would be indistinguishable one from another (Leibniz, 1973).

Remarkably, as if anticipating the universal dynamics, Leibniz, an antipode of Newton, explained the interaction at distance by the composition of local interactions.

The atomistic principles, based on the variety of qualities of the atoms, underline Pattern Theory, in which (informally):

1. Primary atomic elements (generators) have labeled bonds (bond structure), similarly to atoms in chemistry.

2. Generators with similarly labeled bonds form bond couples, thus combining into configurations, similarly to molecules in chemistry. In Grenander's language, the generators **interact**.

3. Both generators and their binary composites (bond couples between them) can be attributed a rich variety of properties, including equivalence classes and numerical values, such as, for example, the acceptor function that defines the selective affinity of generators toward each other. Pattern system can be fine tuned. Analysis and synthesis of patterns relies on heuristics as much as on formalism.

4. In a closed system, probabilities of configurations are determined by probabilities of generators and bond couples, similarly to chemical equilibrium and chemical additivity.

5. Observable images are introduced as equivalence classes in configuration space, similarly to classes and conformations in chemistry;

6. Regularity R is defined on a set of configurations as quartet $R = (G, S, \rho, \Sigma)$, where

G is generator space, S similarity transformation defining equivalence classes in generator, configuration, and image spaces, ρ is bond value relation for coupling bonds, and Σ is **type** of connector graph, which, in essence, is also defined through local properties.

Regularity in chemistry is called *stability* : the property of a chemical structure to be isolated and stored for significant time. In both PT and chemistry irregularity means higher energy as compared with the regular structures.

7. Template is a representative member of an equivalence class of regular configurations: other regular configurations can be obtained from it by group of similarity transformations. Thus, under a particular (rather loose) regularity R , an indefinite number of sociological and economical structures can be obtained by transforming Figure 3 *modulo* R . Given the Periodic Table and regularity of chemistry, the entire chemistry can be built, bond by bond, from any compound and elements, which is, by the way, not only is feasible in the lab but was the actual origin of biochemistry on the Earth. The problem becomes much more complicated in sensory, and especially, visual images.

The realistic character of Pattern Theory makes it highly recognizable as a good “meta-chemistry” for a chemist. I have already discussed the chemical realism of PT (Tarnopolsky, 2003). Moreover, although PT is *algebraic* in the treatment of groups of transformations that identify images as equivalence classes of configurations, the set of generators **may be open**. This idea was expressed by Ulf Grenander in his first large pattern system MIND (Grenander, 2003, p.7):

The set of all generators available to a particular mind will be denoted by G , the *generator space*. As time goes on G may change: new primitives may be acquired, others forgotten, but for the moment we shall treat the generator space as fixed.

This seems like a radical idea for a mathematical system, and, for that matter, even for the systems theory. MIND contains other radical ideas, among them, that only a small part of the generator space (content) is involved into the ongoing transformation of the mind and, moreover,

the content is drifting in a regular (in the sense of PT) manner through the configuration space. It means, in my interpretation, that the mind, unlike the computer (and unlike a robot in AI), has no random access memory: the **most probably accessible memory** is the 1-neighborhood of the generators in the content. The depth of memory can also be accessed, but at lower probability, as a “sudden revelation” or “creative act.” The next state of the content is formed from the generators connected to the previous one. This prevents the degeneration of configurations to negligible probabilities. The mind is a device for self-discipline.

I would interpret Grenander’s MIND as not a point but a **cloud of probability** moving through the phase space of the system. In the present version of MIND the model is, essentially, ergodic, which an evolving LMS system is not: the configuration space changes through inputs, forgetting, and the steps of the Bourbaki’s scale. Of course, ergodicity makes no sense whatsoever for very large combinatorial spaces with times of search exceeding the age of the universe. For example, the pixels of a digital image generate over $2^{1000000}$ combinations.

NOTE: To make a pattern-theoretical equivalent of an open system, one only needs to establish a competition for a limited resource between configurations. Loss of information is an equivalent of dissipation, while acquisition of information can be arranged through the Boolean function of *novelty* (Tarnopolsky, 2003).

The model of MIND reproduces the important property of LMS: the change is local. It means that changes in all sufficiently large system occur in limited areas. To put it differently, significant events in LMS, like earthquakes, are expected to follow Poisson distribution and a large number of simultaneous changes is improbable. What was confirmed by Lewis F. Richardson for wars may be true also for Washington scandals.

Another radical idea of Pattern Theory seems to be directly opposite to the exclusively relational approach. Both generators and relations between them (bond couples) can be associated with labels and numbers, for example, bond values, probabilities, or energies, as well as global **temperature**, which makes Pattern Theory a kind of intrinsically thermodynamical mathematical system, deeply analogous to chemistry. Given the regularity, it invisibly “calculates” its own probability distribution over the configuration space in the same manner the

chemical system “calculates” its equilibrium or proteins “calculate” their folding. Monte Carlo methods are used to compute this equilibrium, which otherwise would require as much computation as protein folding.

The best way to Pattern Theory, with its unique combination of abstraction and realism, is to turn to the original sources. My immediate goal is to see what it can do for history.

The pathway from Pattern Theory to history goes through chemistry, which has been a metaphor for LMS, starting from Leo Tolstoy who regarded big historical movements of people and ideas as fermentation.

6. Chemical kinetics: the short run

I discussed the relation between PT and chemistry elsewhere (Tarnopolsky, 2003). Here I will focus on the concept of transition state from the meta-chemical perspective, i.e., in terms of generators and configurations of PT, which significantly idealizes the real chemical situation.

The concept of transition state (Eyring and Polanyi, 1931) is a very general concept of dynamics.

Transition state theory (TST), introduced by Eyring and Polanyi ... in 1931 as an early attempt to determine absolute reaction rates, is too often considered the domain of the chemist or chemical physicist. However, the transition state (TS) is actually a general property of dynamical systems which involve an evolution from “reactants” to “products.” Such processes include, but are by no means limited to, the ionization of atoms, the dissociation or re-action of molecules, and even the escape of an asteroid from its orbit (Jaffe et al, 2000).

The transition state theory is the central explanatory paradigm of chemical kinetics. It assumes that between configurations A and B on the same generator space the position of equilibrium is defined by:

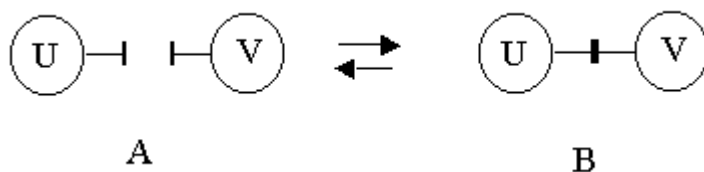
$$[A]/[B] = K_e ; [A] + [B] = C;$$

$$\log K_e = - (G_B - G_A) / kT ,$$

where $[A]$ and $[B]$ are probabilities (or concentrations, in chemical terms), $C = 1$ for probabilities, C is total concentration in chemistry, K_e is equilibrium constant, and G_B and G_A are energies of the two configurations, additive over generators and bonds. They are Gibbs energies $\Delta G = \Delta Q - T\Delta S$ in chemistry, where Q is thermal energy, T is temperature, and S is entropy.

In such a simple system, energy and probability are just two scales—linear and logarithmic—to measure the same parameter of distribution. In real chemical systems, absolute values of energy are rarely observable or calculable and in real complex stochastic systems, the event space is never complete. For all practical reasons, chemists are satisfied with their differences ΔG , often even with the sign of ΔG .

If configurations A and B are formed from only two generators U and V, the transformation consists of bonding and unbonding of the generators:



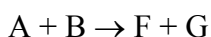
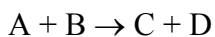
No other configurations are possible and nothing else can happen.

On rich generator spaces, combinatorial configuration spaces, under the same regularity, can be indefinitely large. In this case configurations can be in equilibrium with indefinite number of other configurations (Figure 5).

The chemist tacitly accepts this, but on one condition: the time of equilibration is infinitely large. If the time of equilibration were short, explosive chemical complexity would be unmanageable.

In fact, only a small fraction of all possible transformations runs with any measurable speed. The chemists possesses a large (but not exorbitantly large) collection of heuristics, which allow for limiting the alternatives, ideally, to one, two, or otherwise accept the uncertainty, as in radiation damage of biopolymers. The chemist simply knows that some bonds, actually, most of them, will not change in a spontaneous movement toward equilibrium. Only the fastest transformations can be taken to account.

Suppose, we have two concurrent transformations:



Since the rate of transformation $AB \rightarrow CD$ is proportional to the product of the probabilities (concentrations) of the configurations on the left, the fastest transformation will quickly exhaust A and B and further slow down $AB \rightarrow FG$. The two transformations compete for a limited resource. Nevertheless, if both are reversible, the final result will be equilibrium. By skillfully using what is called thermodynamic (equilibrium) and kinetic (transformation speed) control, and, especially, catalysis, the chemist rides the professional bicycle that falls down when it stops. The living cell is no different: it must run its biochemical cycles in order to stay on the road.

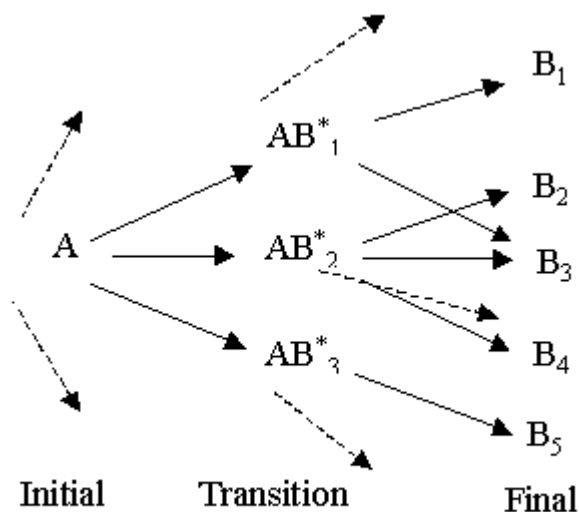


Figure 5 The tree of transformations in chemistry

The key to managing chemical complexity and staying away from combinatorial explosions is in the reaction rate, which for $AB \rightarrow CD$ is expressed as:

$$d[C]/dt = d[D]/dt = K_r[A][B], \text{ where } K_r \text{ is the rate constant.}$$

To explain why rate constant vary and transformation takes some time, the chemist assumes that between A and B on one side of the transformation and C and D on the other side, all four being *regular*, there is an *irregular*—and therefore unstable, ephemeral, and of low probability/concentration—transition state $ABCD^*$, which is neither AB nor CD. It is much less probable and, therefore, of higher energy than AB and CD, so that AB and CD are in equilibrium with $ABCD^*$. The transition state, therefore, is the bottleneck of *real* transformation.

It is easy to see, that this conjecture introduces time into equilibrium thermodynamics where it does not belong. Justifications for this sleight of hand can be found in quantum physics.

In Figure 6 transformation $A \rightarrow B$ ($G_A > G_B$) goes through transition state AB^* . The reverse transformation $B \rightarrow A$ brings the system, sooner or later, to the equilibrium. The appearance of the curve is entirely fictional because it is not observable. Moreover, in most cases, AB^* is not observable either: the entire curve is passed very fast. The bottleneck is caused by the unfavorable position of the equilibrium between A and AB^* .

In social systems, it is the very rarity of a “big” transformation, as the rarity of a formative event in Freudian psychology, that makes it irregular.

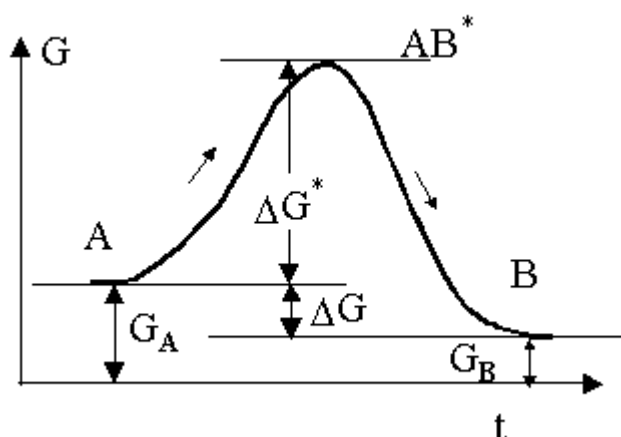


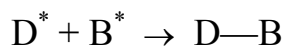
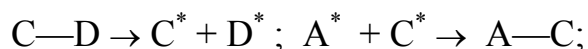
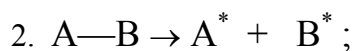
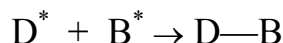
Figure 6 Transition state AB^* between stable states A and B

The fact that the transition state is typically not observable follows from its instability; the instability (short life span, low concentration) follows from its high—as compared with stable initial and final states—energy; the high energy follows from its irregularity; irregularity is most often the result of a loose uncoupled bond or another internal *stress*, for example, because of geometrical *deformation*. The italicized words are used in similar meanings in social psychology (*stress*) and PT (*deformation*), not to mention material engineering. What follows from this causal chain is the notion of regularity and stability as the vehicle of analogy across long distances in knowledge representation.

The sequence of stages, including hypothetical or sometimes observable (for example, by color or magnetic properties) transition states is called *mechanism*.

Example: transformation $A-B + C-D \rightarrow A-C + B-D$ can go through two mechanisms:

1.



In the above mechanisms, all configurations with asterisk, i.e., with missing or extra bonds, are unstable. In $[A\cdots C\cdots D]^*$ the unusual (irregular) dotted line symbolizes irregular bonds. It can be compared with a love triangle, while A^* , B^* , etc., represent the singles eager to find a partner. Let us have in mind, however, that what is irregular in chemistry is perfectly regular in quantum chemistry.

To summarize, in pattern kinetics, irregularity is the key to the probability of a certain direction of change.

7. Equilibrium, kinetics, and catalysis in history

As applied to history, the **hypothesis** is: if two or more alternatives are available, as in Figure 5, what can go through the least irregular transition state, i.e., with the lowest energy, relatively to the initial state, has the highest chances to happen indeed. Of course, the word “probability” is used here metaphorically, as we use the words “probability of rain” talking about weather. It would be more appropriate to use the vague “chances.”

In the long run, however, the outcome is driven by the difference in energy of the initial and the final state. Thus, in the full of pattern trajectories traceable through 2500 year distance in time “*The Peloponnesian War*” Donald Kagan (2003) comes to the conclusion: “In a war of attrition the side that does the most damage must ultimately win.” (p. 75). He obliquely suggests that if the Athens were more offensive against Sparta in the very beginning of the war, instead of taking a defensive position, the outcome could be more favorable for it. In fact, a period of a more active military policy in the middle of the war brought the Athens significant success, lost later.

Similarly, Paul Kennedy believes that the outcome of WWII was predetermined by the economic and numerical superiority of the anti-Nazi allies who, I would rephrase, could inflict more damage. In the short run, the Nazis seemed unstoppable. But the history of the twentieth century is full of conflicts where the superior power could not win.

The final state of a historical conflict, therefore, can be evaluated more or less objectively. However, quoting Kagan, “But reason rarely predominates when states and their people have gone to war, and objective calculations of comparative resources are rarely enough to predict the course of an extended conflict.” (p. 63). People are driven by “fear, honor, and interest.” Besides, as Kagan noted, true democracy can be a big “inconvenience” for a country at

war (p.87). In the first American war of the twenty-first century, the unwillingness of the democratic societies to inflict damage on anybody, including themselves, was unprecedented.

Turning to the most recent events, the Second Gulf War of 2003 against Saddam Hussein had an extremely low transition barrier: the well oiled military machine could be started by a single order, and Iraq had no air defense. The transition to the post-war situation was swift and smooth. The final state, however, had opened a long-run process, with its own hills and valleys of energy landscape, where completely different forces began to act in the war of attrition. Only a historian, however, can offer the postmortem of the final state. While history is in the making, the final state is in the imagination of the leaders and the public for whom the transition state is of a more imminent priority.

Strictly speaking, **historical process has no *a priori* known final state**, which is in full compliance with the view of Prigogine. Extrapolating this principle on history of science itself, however, we **may hope** (exactly because the outcome is not known in advance) to have some better understanding of patterns of history, including the transition and final states, after developing some theoretical foundations and processing the Very Large Chronicle by the apparatus of analytical history. History of science is full of realizations of impossibilities. The way to such understanding lies through analytical history, which was simulated by an ontological question. Similarly, we may ask whether a repertoire of initial, transition, and final states exists. The repertoire may turn out much simpler than we could expect because of the locality of change: historical patterns involve small configurations, as Grenander's *content* involves a tiny fraction of the *envelope*.

Chemical transformations take time because, due to the Maxwell-Boltzman distribution of energies, only a small part of molecules have sufficient energy to cross the barrier of transition state (it is called *activation energy*). Anything that could lower the barrier of a particular transformation would enhance its rate. This is the essence of catalytic effect which can be quite dramatic. The enzyme catalase increases the reaction rate by over 100 times, which reduces the reaction time from years to seconds. This reaction goes to the very end because the removal of the forming oxygen makes equilibrium impossible: Peroxide $\rightarrow$ water + oxygen, or $\text{H}_2\text{O}_2 \rightarrow \text{H}_2\text{O} + \text{O}_2$.

A common misconception about chemical catalysis is that it works as in Figure 1, very much like two hands of an assembly worker (demon), by taking two pieces, connecting them, and then disengaging itself from the assembly. The devil of this picture is in the reversibility of time. The catalyst will enhance both direct and reverse chemical transformation, or, in terms of a match-maker, both marriage and divorce. The mechanism of chemical catalysis is beyond the scope of this paper (a quick view of kinetics, catalysis, and transition state can be found on the Web). If chemistry moves toward equilibrium, while biochemistry does not, it because of the dissipative nature of life: the wheels of biochemical cycles spin in one direction, consuming free energy and ejecting heat. The same fully applies to civilization: micro-events could be reversible—as the prohibition law of 1920 was—but the overall is not—**while dissipation lasts**.

Therefore, we can call *catalyst* any factor that lowers the transition barrier and *inhibitor* any factor that rises the barrier. Thus, the military attack of USA on North Korea is currently strongly inhibited by the geography and resources of the Korean Peninsula, however attractive the final bliss of security looks in imagination. The catalyst is the fear of the consequences of a North Korean contribution to a nuclear attack on the USA. It is easy to imagine the high irregularity of the current transition state and the stress it imposes on the decision makers.

There is another powerful factor that can lower the transition barrier: high temperature, i.e., the intensity of chaos. In times of confusion after a shock of an attack, natural disaster, or mass revolt, the high abstract temperature indiscriminately decreases all differences between the energy levels and flattens out the energy landscape: anything seems possible and the head of Louis XIV falls into the basket.

8. Illustration: Darius against Scyths

Let us consider as an example a fragment of ancient—to avoid any contemporary political bias—history as told by Herodotus (1955).

The story of the Persian march on Scythes, around 500 BC, would make a great script for an action movie if there were lot of action or at least a love story. In fact, there was mostly

inaction: Darius did not manage to engage into a battle with the Scyths. And yet the story is full of suspense. Herodotus gives a vivid account of the struggle of the minds of the opponents that brought the conflict exactly to the point where it started. The story is remarkable by the psychological coherence and explanatory details that show the causation of events. It is both a history and a literary story.

The pattern of the story—the expedition and its return without an accomplished goal—can be seen, probably, in the Vietnam War and some other conflicts of the last half of the twentieth century.

Herodotus gives the lack of allies and any land to protect as the reasons why the nomadic Scythes initially refused to fight. When some of them finally decided to give a battle, it was too late: Darius decided to go home. The reasons for his final decision are stated with high psychological accuracy.

When Darius, desperate of the void that meets him in Europe, challenges the Scyths, they respond with a cryptic message allowing for a multitude of interpretations. The *uncertainty* of situation brings Darius under stress. He is inclined to see the message as the sign of surrender, but Gobryas, his general, sees it as a threat. Next, the equally cryptic behavior of Scyths who abandon the battlefield to chase a hare, makes the stress unbearable and shifts the unstable transition state of cognitive dissonance toward the unfavorable interpretation of the message. This finally prompts exhausted Darius to turn around and go home.

My purpose here is to trace the mechanism of the expedition as a sequence of stable configurations and transition states.

There are at least three outcomes in a war: victory, defeat, and tie. The latter can ensue as result of equal loss or a voluntary avoidance of the battle and return. In the initial simple configuration **Darius—attack—Scyths** we have no data to select the final outcome. We need to build up the complexity of the initial state to decide in which direction it could possibly move.

Thus, Darius is not just a person, but a king, his location is Asia. He possesses a great empire and has nothing to lose but a bit of his prestige. The Scyths have nothing to lose because they are not tied to the land. This makes the conflict a kind of a cold war.

At the beginning of the story Darius only contemplates the expedition. Herodotus supplies us with almost all available (but not always reliable) knowledge about Darius and the Persians, even such details as the thickness of their skulls as compared to those of the Egyptians. We can start, for example with the expansion in Figure 7

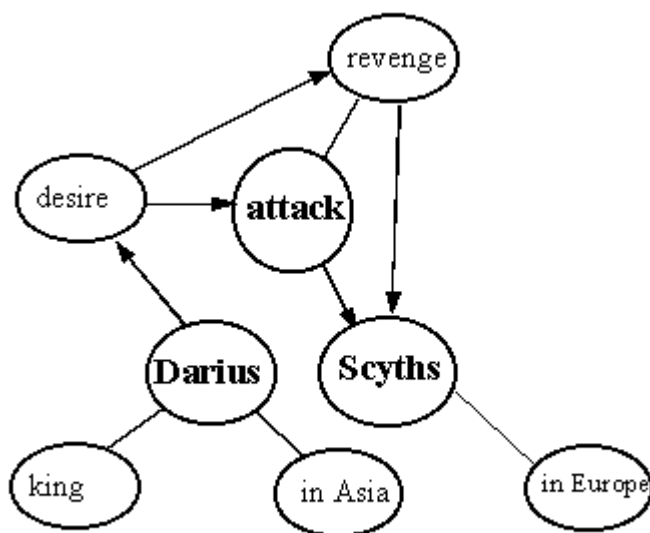


Figure 7. Darius and the Scyths: the seed of an initial configuration

By adding more details we can build an incomplete initial configuration as in Figure 8 . It consists of two sparsely connected parts around Darius and the Scyths. A complete one would include all we know about the events, protagonists, and their physical, historical, and geographical backgrounds. For example, a separate subconfiguration would represent Ionians who double-crossed the Scyths. We do not need this, however, because most of the factors are either irrelevant or remain unchanged.

None of the configurations, graphs, tables, and other representations has any claims for the truth. My purpose here, following the ideas of Ulf Grenander, is to show how this can be done in principle, so that a platform could exist for **debates** possibly leading to a relative consensus typical for natural sciences. As I believe, that type of consensus was in the ultimate vision of Pitirim Sorokin and Vilfredo Pareto in sociology. In is the same way of *naturalization* social psychology has managed to create a platform for discussion and consensus in the area of small groups with the theories of balance (Heider, 1958), cognitive dissonance (Festinger, 1962), etc., having a strong chemical flavor. Apparently, Benedict Spinoza was looking in the same

direction in his *Ethics*.

In the absence of quantification, the measurements can be reduced to ordered and partially ordered sets and approximate scales, called “naïve” in Artificial Intelligence. As a curious example with historical flavor I would quote *Analects* of Confucius (WWW) where the Master builds a partially ordered set of ethical values:

Tsze-kung said, 'What do you pronounce concerning the poor man who yet does not flatter, and the rich man who is not proud?' The Master replied, 'They will do; but they are not equal to him, who, though poor, is yet cheerful, and to him, who, though rich, loves the rules of propriety.' Book I, Chap. XV. 1.

The Master said, 'They who know the truth are not equal to those who love it, and they who love it are not equal to those who delight in it.' Book 6. Chap. XVIII.

In the same way, I measure the irregularity—otherwise, tension or stress—of the situation on the scale from one to four.

The **Table** lists some states of the story. The tension is marked by 1 to 4 red asterisks. The moments of irregularity are those uncertain and short-living transition states where, like in the chemical transition state $[A\cdots C\cdots D]^*$, the rules of regularity are violated. For example, when a decision **is being made** or the protagonists encounter a **puzzle** that does not fit any rational framework.

The focus of the tension, shown by a red circle, usually has two incompatible arrows converging on it (disputes) or two diverging (decisions) arrows of alternatives. Those are Prigogine’s moments when the baker again folds and rolls the dough of the process. In the Antiquity, the baker was a god. Human decisions and actions, of course, may have zones of reversibility.

Figures 9 and 10 present some stressed intermediate states and the final tension-free state of the last decision and a dubious happy end of the safe return.

The intermittent stable and transition states are shown in Figure 11. The “mountain chain” or “roller-coaster” appearance is typical for stories, whether fictional or real. For comparison, Figure 12 portrays the roller-coaster of the French Revolution.

Table: The events and tensions of Darius' expedition

No.	State. D : Darius, S : Scyths	Tension / irregularity		
		No.	Persians	Scyths
1	Darius wants to attack Scyths			
2	Artabanus tries to dissuade D in vain.	1	**	
3	D sets out			
4	D passes two rivers			
5	D Passes Ister. Dispute whether to leave the bridge	2	**	
6	Scythians confer with local people, looking for allies. S decide not to fight D in a battle.	3		**
7	S lure D eastward, over Tanais (Don).			
8	S direct D into non-allied people, to provoke them. Send the wagons north.			
9	D reaches Oarus (Volga), sees no S , and turns back.	4		**
10	S meet resistance of non-allied people.	5		**
11	D send a message to S (to Idanthysus).	6	***	
12	S send troops to Ionians at the bridge, others decide to fight.	7		***
13	Braying of the asses bothers S	8		**
14	S try to delay D 's departure and help him with food.			
15	a bird, a mouse, a frog, and five arrows	9	***	
16	S confer with Ionians, who agree.	10		***
17	Almost a battle, if not for the hare.	11	****	
18	Gobryas: leave the weak, move to Ister			
19	S pursue D , going to the Ister but the armies miss each other			
20	The Ionians decide on the fate of D	12	**	
21	Ionians give false promise to S and destroy only a part of the bridge			
22	S believes the Ionians fro the second time			
23	D finds the bridge broken	13	**	
24	An Egyptian with a loud voice saves D , calling, by his order, Histiaeus, who responds from the other side			

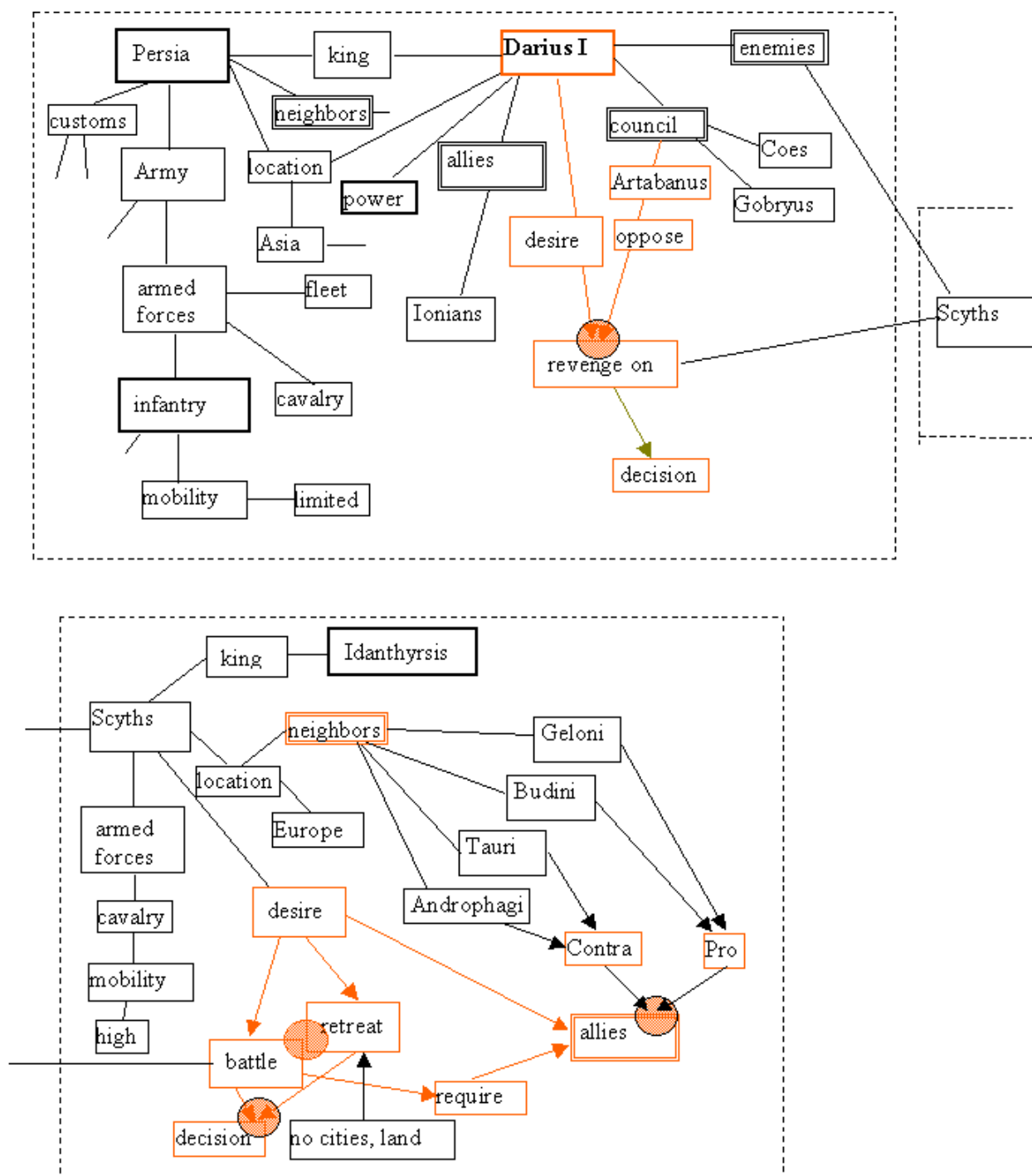


Figure 8. The initial irregularities of Darius and Scyths configurations (red).

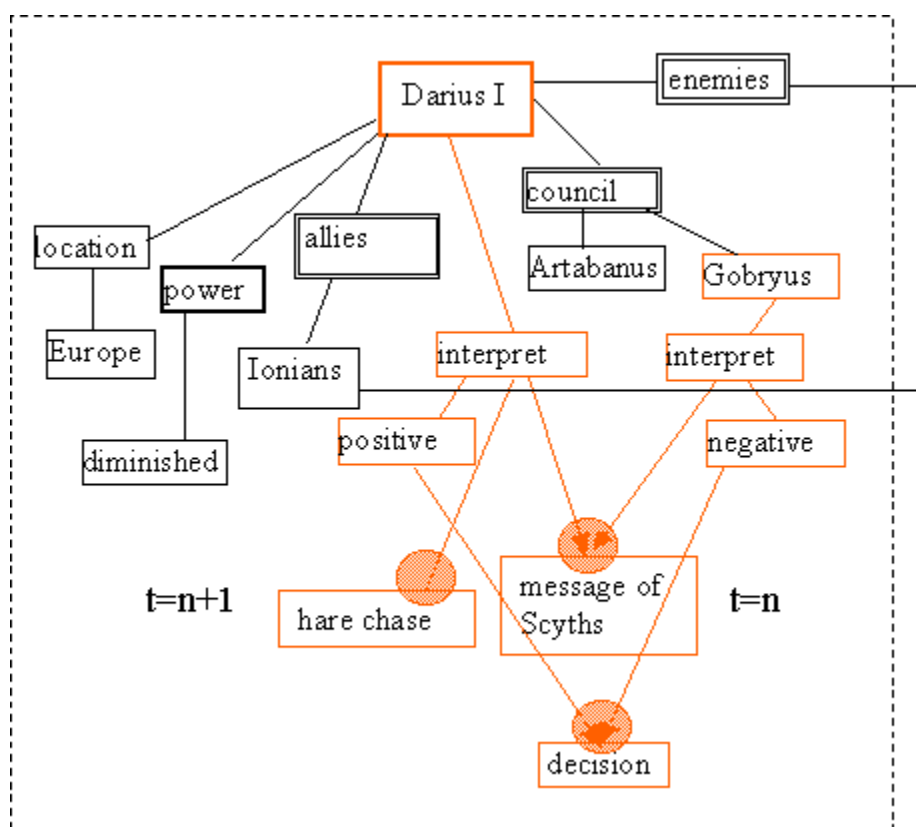


Figure 9. Intermediate irregularities of Darius configuration.

Figure 8 consists of two sparsely connected subconfigurations of Darius, State No. 2 in the Table, and the Scyths, State No.6.

Figure 9 presents States 15 and 17, separated in time, as marks $t=n$ and $t= n+1$ show.

Figure 10 portrays the 20 and 21, i.e., the process of decision-making by Ionians. The final state is still slightly strained by contradictory interests of power and independence.

Figure 11 corresponds to the final state of Darius configuration.

Figures 12 and 13 illustrate the landscape of tension (i.e., relative energy) in a series of relatively stable and transitional configurations for the march of Darius and the French Revolution.

It must be emphasized, that the illustrations aim at the goal of building a platform of consensus, but not the consensus itself, which should be left to specialists.

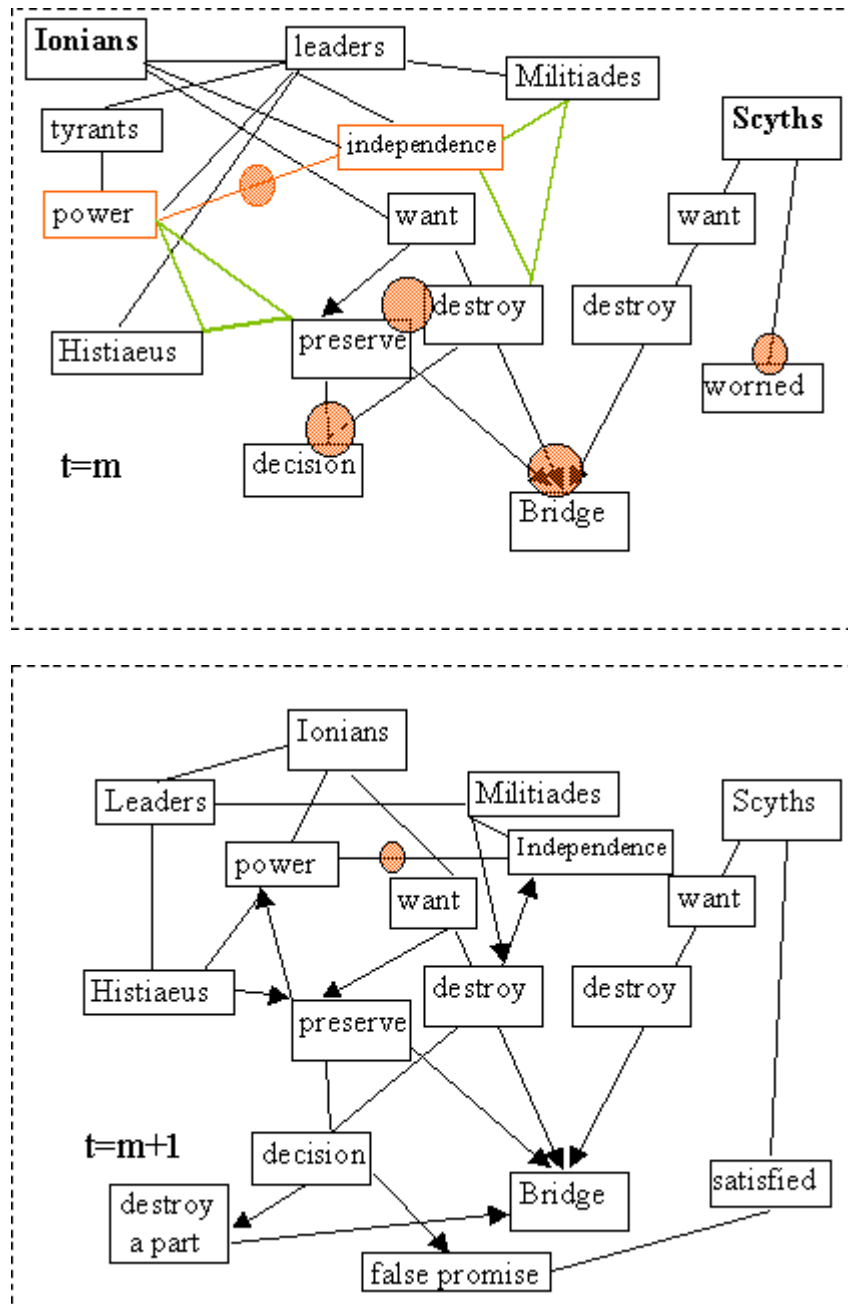


Figure 10. The transition (above) and final (below) states of Ionians.

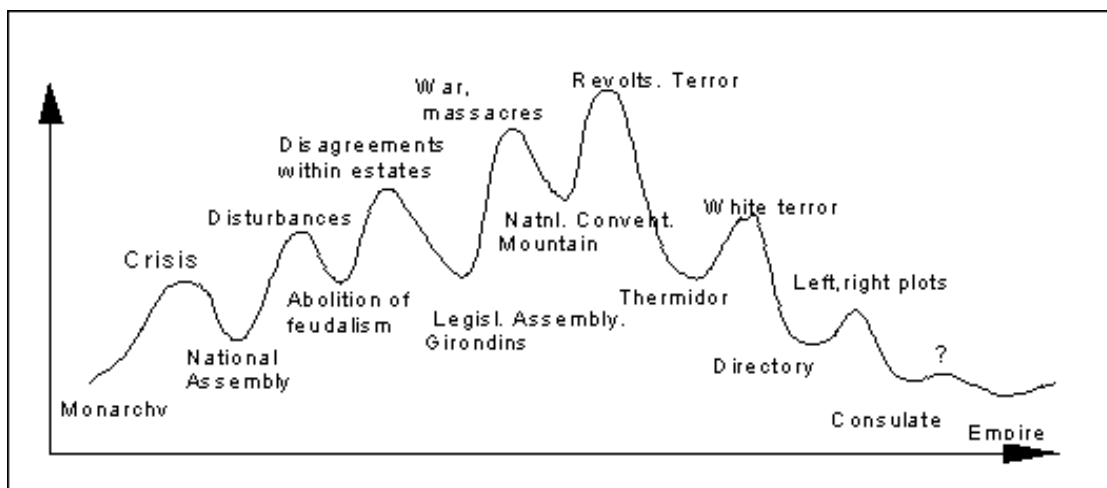


Figure 13. The tension profile of the French Revolution

CONCLUSION

As the historical sketch reveals, a mostly disconnected diaspora of natural scientists interested in history has been forming for some time around the legacy of Rashevsky, Richardson, Tilly, and others, starting from Democritus, Lucretius, and Leibniz.. Analytical history of Roehmer and Syme, as well as the study of patterns of military conflicts of Brecke, have a potential of becoming active centers of the “naturalization” of historical research.

A conundrum of the existing formal approaches to complex systems is the use of closed mathematical structures for representing open irreversible systems. Pattern Theory is suggested as another entry in the inventory of approaches to history. It could be a member of a future club of complementary concepts and methods.

Pattern Theory, with its atomistic realism, flexibility, and preservation of semantics, is uniquely positioned for developing a general representation and modeling of Very Complex Open Systems, such as life, mind, and society. The first point of the application of Pattern Theory to history can be transition state characterized by its irregularity.

Analytical history and large historical databases can create the medium where the ideas of Pattern Theory can be tested.

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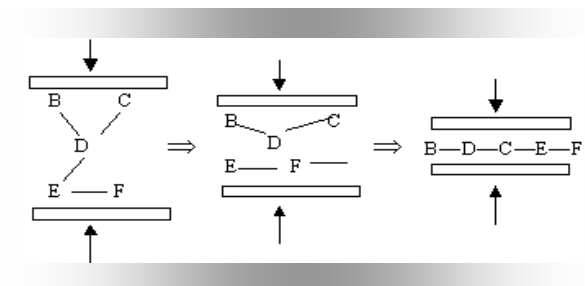
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TIKKI TIKKI TEMBO

The Chemistry of Protolanguage

Yuri Tarnopolsky



2004

Keywords: protolanguage, language origin, language evolution, speech generation, chemistry, chemical nomenclature, linearization, Pattern Theory, Transition State Theory, complexity, Ulf Grenander, George Zipf, Noam Chomsky, Joseph Greenberg, Mark Baker, Manfred Eigen, Ilya Prigogine, Walter Ross Ashby, René Thom, George Hammond, Robert Rosen, axiom of closure.

ABSTRACT

Protolanguage (Derek Bickerton) in linguistics corresponds to an evolutionary stage preceding the grammaticalized language as we know it. It could be possible to reconstruct the principles of protolanguage by turning to most general principles of evolution in a larger picture, of which chemistry is a relevant part. Both linguistics and chemistry are discrete combinatorial systems. Considering the chemical origin of life, chemical analogies might offer some insight into the origin of mind, language, and society, all of which developed on the platform of life. The conceptual basis for discrete combinatorial systems, including chemistry and language, can be found in Pattern Theory (Ulf Grenander) where ideas, utterances, and molecules are *configurations*. To draw the parallel further, chemistry uses its own *language* of chemical nomenclature to represent non-linear molecular structures as linear strings of symbols. Chemistry pays particular attention to the intimate mechanisms of structural transformations. A tentative concept of the mechanism of protolanguage generation is suggested as kinetically controlled linearization of a typically non-linear observable configuration through a non-observable thought. Generation of linear expressions in protolanguage is viewed as a process of generalized chemistry, going from a typically non-linear initial state through a transition state toward the linear output, under the constraint of a maximized preservation of configuration topology.

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The words and verses differ, each from each,
Compounded out of different elements...

Lucretius (*De rerum natura*, II)

The order and connection of ideas is the
same as the order and connection of things.

Spinoza (*Ethica*, I, VII)

1. INTRODUCTION

Mark S. Baker in his book *The Atoms of Language* (Baker, 2001) drew a consistent analogy of linguistics with chemistry. Within the *Principles and Parameters* framework, a language is similar to a chemical element in the sense that it is a combination of certain parameters. Baker acknowledged that most people would associate **words** with atoms of language, but he simply put this view aside as “correct—in one sense.” (Baker, 2001, p. 51). He was, of course, right, pointing to the Periodic System as a metaphor for the combinatorial nature of language. Moreover, the book manifested the true chemical spirit: it was built around numerous **observable** linguistic examples, as any typical chemical monograph is built around hundreds of structures and their transformations.

For a linguist with comparative interests, a large part of the fun of doing linguistic research is searching out all the fascinating, deep, and intricate differences in how languages work. Indeed, the only thing that gives a comparable thrill is discovering the deep and fascinating ways in which they are all the same. (Baker, 1995)

The above quotation reveals to me a kindred soul: I could sign it if *linguist* was substituted for *chemist* and *molecules* for *languages* because chemists deal with concrete

individual and observable objects, while parameters are rather abstract structural invariances.

It would be unbecoming for a linguist to say “It’s Greek to me” about chemistry, anyway, but there is some genuine feeling of kinship between both areas. Linguists evoke chemistry as the science epitomizing not only complexity but also its successful conquest.

The kinship was prophesized long before the birth of chemistry and after the birth of the famous Greek Democritus:

The words and verses differ, each from each,
Compounded out of different elements—
Not since few only, as common letters, run
Through all the words, or no two words are made,
One and the other, from all like elements,
But since they all, as general rule, are not
The same as all. Thus, too, in other things,
Whilst many germs common to many things
There are, yet they, combined among themselves,
Can form new who to others quite unlike.
Thus fairly one may say that humankind,
The grains, the gladsome trees, are all made up
Of different atoms (Lucretius, 1958, Book II).

Chemistry, on its part, has been using extensive linguistic parallels for nucleic acids and proteins since the discovery of their relation. Moreover, much earlier, chemistry developed its own tongue with a lexicon heavily borrowed from Greek and a refined grammar with codified flexions and word order.

Mark Baker’s book was the last drop into the bucket of observations that I had accumulated over a significant time. This paper is an attempt of a chemist to view words as atoms of **a chemistry**.

I am a chemist without any linguistic credentials whatsoever, but with a life long interest in languages. I am, to a variable degree, familiar with properties of such languages as Russian (native), English (current), German (studied at school), French, Hungarian, Japanese, Hebrew, and a few others. My very limited hands-on experience with the non-Indo-European languages, as well as a better (but by no means perfect)

knowledge of both Indo-European but diametrically opposite English and Russian, persuaded me that, with all the striking differences in their design, all languages perform the **same function** with the **same means**. Neither the opulence of Bantu languages, with their classifiers and suffixes, nor the intricately woven ribbons of the Na-Dene verbs could shake my conviction. The function is a representation of a non-linear “source,” whatever it is, and the means is an optimal linearization of the non-linear representation. When I had looked into linguistic literature, I found plenty of support.

The vocal-auditory channel has some desirable features as a medium of communication: it has a high bandwidth, its intensity can be modulated to conceal the speaker or to cover large distances, and it does not require light, proximity, a face-to-face orientation, or tying up the hands. However it is essentially a serial interface, lacking the full two-dimensionality needed to convey graph or tree structures and typographical devices such as fonts, subscripts, and brackets. The basic tools of a coding scheme employing it are an inventory of distinguishable symbols and their concatenation. (Pinker and Bloom, 1990).

For over twenty years I have been watching the development of Pattern Theory (Grenander, 1976-2003), sometimes from a close distance, regarding it as a general approach to complex systems consisting of atom-like elements and connecting bonds. It became clear to me that this mathematical theory of everything nicely covered not only molecules and languages but also every discrete combinatorial system we could come in touch, and did it with an unprecedented combination of generality and realism.

Furthermore, I have witnessed the entire genesis and evolution of the science of complexity, starting from Prigogine (1984) , who formulated the most fundamental principles of complex natural systems such as life, mind, and society, and further toward Artificial Life (Adami, 1998) where languages and molecules were of the same kin already at the inception (Eigen, 1971-1979). “Natural” here is the opposite of “artificial,” such as virtual reality where people can walk on the ceiling and turn into wolves right before your eyes.

I am also familiar with the language of musical notation, a couple of programming languages, and, due to my profession, with the curious language of

chemical nomenclature invented by organic chemistry to verbally communicate the non-linear molecular structure.

Finally, the language of poetry—rarely spoken in everyday life—is my bonus pass to a gym where one can exercise linking distant meanings and close sounds.

The enormous literature comprising computational, formal, traditional, and historical linguistics, Artificial Intelligence, Artificial Life, mathematical structures, physics of open systems, chemistry, and details of Pattern Theory is probed here only highly selectively and superficially. The growing but still manageable bibliography on language evolution and computation has been nicely collected and presented at the website of University of Illinois at Urbana-Champaign (Language Origin, WWW).

My intent is not to formulate a theory—this should be entrusted to professionals—but to offer a new (but organically grown!) spice for the boiling cauldron of linguistic ideas. Whoever likes the aroma can use it for meditation, inspiration, and, who knows, for some fun time after a Ph.D. thesis. I wish to share a widest and most comprehensive—an illusive but honorable goal—view of the intellectual jungle where linguistics and chemistry are of the same blood. In short, if it all boils, then down and up to Pattern Theory.

I believe that my outsider status, as well as the claim for a larger picture, grants me the privilege of choosing my own far-from-academic style—which is just being natural. I cannot walk on the ceiling. But I have another uncommon gift: I see the world with the eyes of a chemist.

I further refer to the following key figures of painting a large picture with language in the landscape: Lucretius, Ulf Grenander, George Zipf, Manfred Eigen, Ilya Prigogine, Walter Ross Ashby, Rene Thom, George Hammond, all of them, except Lucretius and Zipf, natural scientists and mathematicians. I mention other profound linguistic thinkers in the main text. I am sure most of the ideas of this paper can be found in the literature and I apologize if I failed to find them.

I widely use the WWW sources where it is possible. They may die out with time, but a peculiar life-like property of the Web is that the new ones will be cooked, could be searched for, and found, garnished with ads. For better or worse, money will never be out of the larger picture but I hope it will not fill up the entire canvas.

2. PREVIEW OF MAIN IDEAS

My initial thesis is: to compare language and chemistry we have to view them as natural phenomena within a larger picture.

Language is embedded in human psychology and society, and is ultimately governed by the same principles as galaxies and mesons. (Hurford, 2003, p.38)

We shall look at both from a more general view than either chemistry or linguistics and in both linguistic space and evolutionary time.

From the evolutionary perspective, there must be a fundamental truth in the concept of protolanguage (Bickerton, 1990, 1995, Calvin and Bickerton, 2000), from which the full-blown languages evolved. Bickerton's earlier vigorous and polemic book (Bickerton, 1981) was full of important large-picture ideas, some of which will be echoed here. The recent collective volume (Language Evolution, 2003) with Bickerton's contribution, summarizes the current status of the problem and will be often referred to.

Protolanguage is not just a playground for imagination. The use of protolanguage, within the framework of algorithmic AI, has been discussed and attempted for a simplified communication between a human and a computer or robot, see for example, Varshavskaya (2002) and Billard (2002), but the results were not too encouraging.

If there is something truly universal for all languages, from pre-protolanguage to the modern street slang to the flashy lingo of *The New Yorker* art reviews, and from

English to Mohawk, it must be so not only in space but also in time. Here we will be looking for a **universal property of modern language, applicable also to protolanguage and its subsequent evolutionary record**. By definition, it is something that cannot be found in either extant or extinct formal structures, but only diachronically: along the time axis.

If we deal with a non-grammatical protolanguage we have to abandon all the theories of fully developed language, together with all the contrived and artificial examples and even the entire ontology of the past several millennia of culture. This is a big relief because it is difficult to find a non-trivial linguistic statement which has not been contested during the linguistic wars in which a chemist has no part.

The form of dialogue, which had lost its appeal since Plato, Galileo, and Bishop Berkeley, was revived by Juan Uriagereka (1998) in his popularization of minimalist syntax. It inspired me to design the following introductory exchange, where vague words, like “typical” or “source,” are used to avoid obdurate head-on statements and meaningless terms such as meaning (why meaningless? to define meaning, you have first to define meaning).

1. **Q.** What is typical for natural sciences?
 A. They deal with observable objects and processes.

2. **Q.** What is typical for a natural process?
 A. A certain parameter, for example, energy, changes in a preferred direction, unless an external influence prevents the natural course. The apple naturally falls down, if not caught by a human hand.

3. **Q.** What is typical for molecules and utterances?
 A. Both are **structures**. Most generally, structure (not in the sense of “mathematical structure”) is a set of elements and a set of pairs, i.e., connections between some of them. Graph, especially colored and labeled, i.e., with values or markers at arcs and nodes, is a fair image of structure. Configuration of Pattern Theory is a better one.

4. **Q.** Atoms interact. How do words interact?
A. They form linear strings: utterances. Some strings stick together, which reveals the affinity of the words to each other, and participate in verbal exchange. Other strings do not hold together and cannot be used.

5. **Q.** What is the immediate source of the utterance?
A. Thought. We do not know what it is except that it is a mental state or process. A thought, unlike an apple, is never shared and never observed—yet. (Very fortunately. But for how long?).

6. **Q.** What is the source of the thought?
A. **Observable** reality: thing, situation, object, process, relation, sensation, information, sign, phrase, text, image, cue, signal, question, remark, utterance—anything that could be shared or witnessed by at least two people.

8. **Q.** What is the relation between a thought and its expression as an utterance?
A. Since we have no means of observing a thought, we have to go to the **source** of the thought outside the individual mind. The **image** of the source preserves topological relations between components of observable reality. The structure of thought is, **hypothetically**, not necessarily linear. Structures in PT (configurations, images, patterns) and chemistry are typically non-linear.

9. **Q.** What happens when an utterance in protolanguage or language is generated from its source?
A. **Linearization** of a typically non-linear configuration. In any case it must happen somewhere between the source and the expression like “I see Og take Ug meat” using Bickerton’s example (Calvin and Bickerton, 2002).

10. **Q.** What is protolanguage? What is full language?
- A.** **Protolanguage** is a linearization of thought in which the binary connections in the source are represented by pairs of adjacent words, which may not be possible for all pairs in the source.
- Language** is same as protolanguage, but the connection can be expressed, in addition to word order, by means of morphemes, regardless of the adjacency.
11. **Q.** How does language emerge and evolve from protolanguage?
- A.** By mutation and replication in populations of utterances communicated in a social group. “You say potahto, I say potato.” Language **is** a form of life. You say nukelar, I say nuclear.
12. **Q.** What is typical for a form of life?
- A.** In addition to replication and mutation, there is the important property of homeostasis, i.e. the ability to restore peace after turbulence and to minimize a deviation from “the middle road,” often by taking another evolutionary pathway.
13. **Q.** What do language and chemistry have in common, apart from being discrete combinatorial systems?
- A.** First, there is a stage of the fleeting and **non-observable thought** in language generation (it cannot even be remembered if not put into words) and there is a fleeting and typically **non-observable transition state** in a chemical transformation. Second, chemistry has a distinct language of its own, intended to **linearize** nonlinear chemical images.

Next, some points of the dialogue will be expanded in a series of chapters, without going into too much detail, because what truly relates both chemistry and linguistics is the zillion devils in the details.

Finally, the above dialogue will be illustrated by computer-aided examples of linearization at the level of a hypothetical protolanguage called Nean. The computer, however, will act in the dumbest role of a generator of random numbers and could be

substituted just by flipping coins. To attribute any algorithm to a genesis of a natural system equals to designating a creator.

My concluding thesis is that an almost mindless process of linking two atomic names together (Ug big) because the atoms are linked in the source, could be sufficient to launch protolanguage. The random and mindless process of natural selection in the populations of utterances could be sufficient to launch the evolution of full language with its rainforest exuberance of species.

3. CHEMISTRY AND LINGUISTICS: SISTER SCIENCES

It is no wonder that chemistry and linguistics could be jointly found at over 800,000 web pages (in 2003) because any university is a natural place for them to rub shoulders. It is much less common to meet both on the same page of a scientific text. Nevertheless, an acquaintance has been struck about half century ago when chemists compared strings of amino acids and nucleotides with lines of text. Today the Web search for **DNA + language** delivers almost 1 million sites. “DNA linguistics,” as it is called, has become a largely independent direction of research (Searls, 1992).

The time around 1950 was a period of extensive planting of new ideas. The concept of Artificial Intelligence, including automatic translation, was formulated. The application of the idea of **transition state** to molecular structure by George Hammond completely revolutionized chemistry. It was also the time of the articulation of the science of complexity by Ilya Prigogine, the arrival of the “extravagant” and “controversial” ideas of George Zipf, and the advent of the formal linguistics of Noam Chomsky. (I believe that the incredibly fruitful time was the aftershock of the WWII: the soil was fertilized with the ashes).

Marc Baker’s book (Baker, 2002) is only one evidence of the interest in chemistry on the part of linguists, although the most significant one. There are other examples of a mutual curiosity.

At the conference *Language as an Analogy in the Natural Sciences* held in Munich in 1997, the chemist Pierre Laszlo presented an essay *Belaboring the Obvious*:

Chemistry as Sister Science to Linguistics. Laszlo (1997) emphasized binary mixing and combining as the way chemical experience was acquired throughout history.

L. Vlasov compared more common in nature metals and less common non-metals with consonants and vowels, expanding the following metaphor:

Nature speaks to us in the language of chemical compounds. And each of these is a sort of combination of chemical "letters," or elements occurring on Earth. The number of such "words" exceeds three million. But there are only just over a hundred "letters" in the chemical "alphabet." (Vlasov, 1970, Story No.20).

The following was addressed to students of chemistry: "Learning organic chemistry is like learning a new language, a language that is both verbal and pictorial" (Ege, 1989, p.2). So, don't be afraid. Chemistry is fun.

Chomsky (2002) used the comparison of the burgeoning descriptive linguistics with chemistry to express optimism in developing a compact theory after a sufficient body of knowledge has been accumulated.

Chomsky noted that chemistry had achieved understanding of the nature of its invisible objects through the union with physics, which has not shaken the factual knowledge itself. It implies that a further advance in linguistics may depend on including it into a **larger picture** of the world drawn by natural sciences.

Mark Willems entitled his doctoral thesis in graph-theoretical study of semantics *Chemistry of Language* (Willems, 1993). Following his lead, Liu (2002) took up *The Chemistry of Chinese Language* as the title of his thesis. Both dissertations expand the research in "knowledge graphs" initiated by Cornelis Hoede at the University of Twente, the Netherlands. His compact lecture, available on the Web, is an excellent introduction into graph theory, knowledge graphs, and the larger picture (Hoede, 2003).

There are countless ways of representing knowledge, meaning, and logic of an expression. The vast literature on ways and uses of representing a sentence as a graph makes me think that there is simply no way to prefer one to another and more can be invented. It also tells me that we do not know what thought is but are afraid to admit it.

The concept of chemical structure has been ingrained into chemical thinking for almost 150 years. Generically, it means the following (wording could slightly differ):

Properties of a chemical compound depend on the **properties of the constituting atoms and the way they are put together.**

Compare that with:

The meaning of an utterance is some function of **the meanings of parts of that utterance and the way they are put together** (Kirby and Christiansen, 2003).

Quoting the Nobel Lecture of one of the founders of modern chemistry (Pauling, 1954):

In 1861 Butlerov, making use for the first time of the term "chemical structure", stated clearly that the properties of a compound are determined by its molecular structure, and reflect the way in which atoms are bonded to one another in the molecules of the compound.

Probably, much more scattered testimonies of affinity could be found, but the last one is strong enough.

I would add some personal observations. Most linguists and chemists deal with material evidence: speech and text are as completely observable as molecular structure—at least by the modern means of analysis. Theory in both areas, however, deals with structures beyond observation. Finally, the material evidence is enormous in size, but by no means infinite, whatever the linguists may say in their strange and pervasive obsession with infinity. See, for example, Studderd-Kennedy and Goldstein (2003).

4. NOAM CHOMSKY AND JOSEPH GREENBERG

Linguists sometimes speak the language of chemistry without even realizing it. But can we speak the language of linguistics?

In Molier's *Le bourgeois gentilhomme*, a play with linguistic connections, Monsieur Jourdain was surprised to learn that he had been speaking prose all his life. A shock—rather than surprise—may expect a natural scientist entering the world of formal linguistics explaining how we speak, prose or poetry.

What follows are some impressions of a skeptical ignoramus like myself, pumped up for the sake of performance but without any malice. I am just trying to prepare the soil of Pattern Theory for the seeds of both chemistry and linguistics.

The Rhyme and Reason by Juan Uriagereka (1998) was intended as an encyclopedia of formal linguistics for an outsider like myself. It reads as sometimes irritating but irresistible spoof of Dante's *Inferno*. Any delusions about the language one has been mindlessly speaking since childhood are supposed to be cured by elephantine doses of proprietary purgative terminology, strangely duplicating the most common words of our daily usage. Here is an example I found in References (Uriagereka, 1998, p.636):

Uriagereka, J. 1994. Government restrictions on Basque movements. In *Syntactic theory and Basque syntax*, edited by J.I.Hualde and J. Ortiz de Urbina. University of the Basque

When (in 2003) I search the Web for all the words in the title, over 2600 links pop up. When I subtract from the search *linguistics* and *Uriagereka*, the remaining 2450 links deal with political restrictions on Basque separatism in Spain.

To me, an ignoramus, the minimalism sounds as a maximalist version of Zen Buddhism with koans like “empty category is not empty.” The giant book’s layout leaves almost half of it just blank, making one wonder if this is a hint to solving the koan.

For an outsider it is hard to chase away the prophetic vision of Herman Hesse in his *The Glass Bead Game*, which, in my opinion, anticipated the postmodern world obsessed with repertoire and performance and indifferent to substance and spirit. A look at the original works of the formal school shows the state of permanent flux, debate, elimination, and invention, for which the *Magister Ludi* himself is not always responsible. Paraphrasing Goya, the sleep of context multiplies monsters.

The Chomskian linguistics looks to a chemist like a Gothic bestiary of creatures, one more bizarre than another, living in a haunted castle where the zombies of *Trace* and *Empty Category* drag their ghostly existence. This world is not for the faint of heart: like in a horror movie, as soon as you, *Bound in Chains*, have beheaded the common *Merge*, the towering *Supermerge* assails you from behind. Furthermore, after you have somehow tackled the midsize *Label*, a peewee *Sublabel* crawls into your pants, and behind the disabused *Projection*, the monster of *Superprojection* *Raises* on its hind legs. But wait, there is also the bloodcurdling *Superraising*, even before the end of Part One.

Well, I get some understanding, if not support, from an outstanding linguist:

We all speak at least one [language] , that one we acquired without a lick of conscious effort, and most non-linguist, in the unlikely event that they opened a copy of *Linguistic Inquiry* or *Natural Language and Linguistic Theory* only to find stuff every bit as hard going as genetics or quantum mechanics, would in many cases react by saying ‘What’s all this nonsense about? Why are they making such a fuss about something that’s perfectly simple and straightforward?’ Bickerton (2003, p.77).

The growing area of language evolution and computation, however, carries a clear promise to create a new, lighter, funnier, but incomparably more complex and technically intricate post-Gothic world, shielded from a curious trespasser by large and unpublished computer codes where, by definition, nothing is either minimalist or made of atoms.

And yet the minimalist *Inferno* left a definite trace in my chemically pre-complexified mind: there must be some deep (*ergo*, simple) truth in the entire approach.

The “naturalization” of atoms in chemistry and, later, physics, as well as genes in biology, was a result of processing numerical experimental data. It is the absence of numbers that makes the generative linguistics a nightmare for the natural scientist.

Nevertheless, knowing well that mathematics is not only about numbers, and responding as a chemist to the teasing call of my “sister science,” I see more than just vague parallels between formal linguistics and chemistry. I have a feeling that Noam Chomsky saw and tried to solve a really monumental scientific problem much ahead of time. The right time, probably, has not yet arrived: the fifty year old artificial intelligence, while beating the grand masters at the chess, still generates ridiculous translations. I feel that Chomsky’s appeal to chemical experience is justified.

It is true that the chemists went through a similar stage. The chemical concept of atom, as speculative as genes before molecular biology, had been introduced by John Dalton around 1808, but it took exactly one hundred years before Rutherford could put some physical flesh on the surreal invention of the mind. After that, about fifty years of theoretical maturation followed. For the remaining half century, chemists have quietly immersed into applications and their monetary rewards, now even sending ripples through the stock market with the dotcomoid nanotech.

There is another, more successful than AI, area with a similar childhood: the chemistry-based molecular biology. Formal geneticists were able to map the distribution of genes in chromosomes at the dawn of the twentieth century without a slightest idea of what either gene or chromosome actually was, simply by comparing the observable features of progeny with those of the parents and counting some numbers. The Chomskian linguistics is strikingly similar to the pre-DNA formal genetics (now called transmission genetics), in which an enthusiast can even find parallels between ~~Allove~~ and

Merge of linguistics and the **crossing over** and **linkage** of transmission genetics. The dramatic (and probably lethal) difference is that formal linguistics is based on an idealized standard of language, which we (not having blood royalty in America) can never hear around. The formal genetics, on the contrary, was based on the study of observable **deviations** from the idealized standard biological type. This is how the tiny fruit fly worked for genetics when the frequencies of mutations were counted.

After applying the Ockham's razor—with the barbarism of an ignoramus—to the dense growth of formal linguistics, I (together with some linguists) see the main problem that formal linguistics deals with as the linearization of the non-linear, see Figure 4.1. This is like extruding the globe of dough through the spaghetti-making machine, for which you need to apply some effort.

There is the unobservable “message” (my copout, to avoid terms like meaning, content, and knowledge) and there is its strictly linear verbal expression. The message is not necessarily linear but the expression is. How does the mind do it? For example, how could Shakespeare put on paper his mental images of the story of Hamlet, with its intricate relations, moves, and physical collisions?

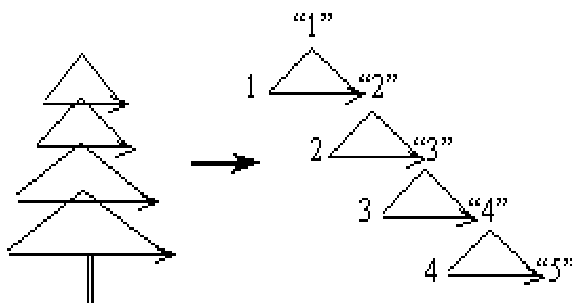


Figure 4.1. Linearizing a tree

The simplest part of the problem is to portray the development of the story in time. This is done regardless of the language, by arranging consecutively the descriptions of events. The chain consists of phrases. For example, a primitive Hamletesque story could go like this:

Enter Ug and Og. Og takes Ug's meat. Ug ponders whether to kill Og. Ug kills Og. Ug dies of spoiled meat.

The drama of the story is in the unexpected consequences. The linguistic drama starts each time when a single link of the diachronic chain must be constructed. There could be several alternatives and which one will be realized creates the suspense in the mind of the cave Shakespeare.

Within the formal framework, it is useless to ask, as a chemist would, what real process stands behind the schema, what its driving force is, how long it would take, how it starts, proceeds, and ends, as well as what the word and its boundaries are, and how we form the initial array of words. Nevertheless, the core of formal linguistics has the power of a well-formulated question which is half the solution.

It is hard to miss the similarity of the problem of linearization to the problem of projection in our perception of visual images: the complex 3D object turns into a flat image on the eye retina. For the humans who, like greyhounds, get most of information from vision, language seems to be an extension of vision in the sense that the same kind of topological many-to-one mapping has to be performed. Language can be called a collective vision. (What is TV? Corporate vision?).

I absolutely do not intend to criticize the formal grammar. Atoms were criticized, too, and, for that matter, what sound idea was not? Just the opposite, I would like to formulate the points of the formal theory that not only make sense but also appeal to a chemist who has survived **Superprojection** and **Sublabel**.

1. **Binarity**. The basic relation between words/atoms is binary in X-bar and chemical bond. Not only there is an attraction between some words, but there is also a bond between groups of words, which tend to stay within the group, as a swarm of midgets (subjacency).

2. **Linearity**. The output of a certain process is linear. This means that a certain typically non-linear structure undergoes a structural transformation, as in a chemical reaction.

3. **Optimality**. The natural direction of the process is toward a minimization of a certain parameter, as in chemical reaction going toward in the state of equilibrium. This point is not exactly a part of the formal framework but it snugly fits the picture and is embraced by Chomsky.

On this positive note, let us now take a peek into the world of Joseph Greenberg who was also attacked and vilified in his time and for the same reason as Noam Chomsky (and may I add Charles Darwin?): his conclusions about evolution of languages were beyond a direct proof. After the sulfurous inferno, however, the world of Joseph Greenberg brings the revitalizing smell of the rhubarb pie to the nostrils of the natural scientist who has just been zenned by Ug, sorry, UG (Universal Grammar).

In the Semitic languages the verb tenses are marked by varying vowels, usually, around three constant letters of the root, as in Hebrew (read Hebrew characters right to left):

אני כותב	אני כתב	אני יכתב
ani kotev	ani katav	ani iktov
I write	I wrote	I will write

The root of the verb is ktv, כתב. The additional ambivalent letters ך and ן are sufficient to distinguish between tenses in writing, without explicitly indicating how the words are pronounced, which could be done by diacritic signs. The signs, absent in the examples, are written in Hebrew and Arabic only when absolutely necessary. The last vowel of the verb between ן and כ is not hinted in any way. The **heard but invisible** vowels, therefore, define here the tense, which in writing is marked by adding some **visible but not heard** letters from a limited set.

Figure 4.2 presents the top left hand corner of Table 1 from Greenberg (1990, p.368). The table contains the frequencies of binary occurrences of the first and second consonants of three-letter roots of 3775 Arabic verbs. The work was stimulated by the previously well known fact that Semitic roots do not typically contain identical first and second consonant, while no such restriction exists regarding the second and third ones. Greenberg presents two more tables with correlations of II-III and I-III consonants, which exhausts the matter.

The numbers in the Figure 4.2 are quantitative measures of occurrences of initial pairs of root consonants and they can be converted into probabilities, although the list of all verbs is not a natural system for a natural scientist. It is like a list of all animals in a

forest without their actual numbers. Nevertheless, some conclusions can be drawn from the frequency of a combination of a long neck with long legs or hooves with horns.

What the Table shows is a Shakeaspearean play of affinity and animosity between consonants. The two identical initial consonants categorically refuse to stand side by side, as the arrow along the diagonal zeros indicates, but there are also definite areas of affinity, as around consonante n (No. 12). It could be seen from another Greenberg's table that the last two consonants do not mind being twins.

		II	p	h	b	f	x	y	q
I	1	p	0	3	2	0	3	0	5
	2	h	0	0	0	0	0	0	0
	3	h	0	0	0	0	0	0	8
	4	f	0	3	0	0	0	0	10
	5	x	0	0	0	0	0	0	0
	6	y	0	1	0	0	0	0	0
	7	q	1	3	6	11	0	0	0
	8	k	3	5	4	5	0	0	0
	9	g	3	7	6	5	0	0	0
	10	r	7	9	7	10	4	7	13
	11	l	3	8	12	8	5	6	11
	12	n	6	14	10	12	10	11	21
	13	s	4	7	8	7	5	5	7
			d	3	4	4	3	1	3
			s	5	8	12	8	9	1
			1	2	3	4	5	6	7

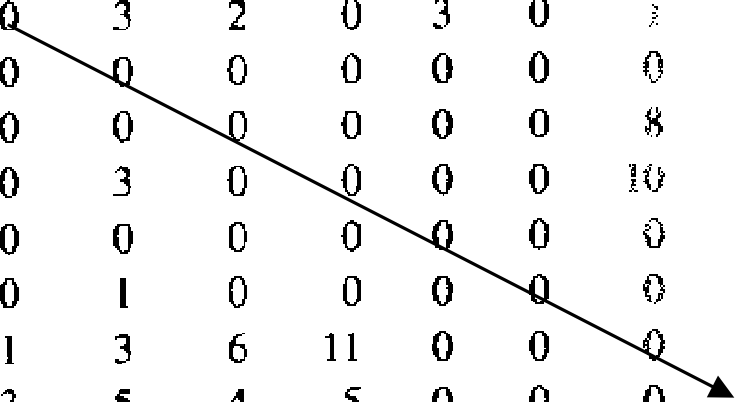


Figure 4.2 A corner of one of Greenberg's tables

Analysis of this kind was one of the first exercises of the newly mastered power of computers (Shannon, 1948). Shannon measured the frequencies of letter and word

pairs and synthesized artificial texts. Greenberg, however, did his work entirely by hand, as, by the way, Zipf did his. The frequency matrices of the type explored by Greenberg and Shannon are linguistic fingerprints. Like DNA analysis, they can be used for recognizing kinship between natural languages as well as styles of individual writers. Among other applications of frequency matrices are the fingerprints of musical styles.

As a non-linguist, I will use the single old paper of Joseph Greenberg, published in 1950, the remarkable time with all the planets in the most auspicious layout for great ideas and the computers in the prenatal fetal position, to illustrate a principle important for both chemistry and linguistics. Scores of modern works are running off the computer mill today.

Shannon's game of generating texts from the probabilities of letter and word pairs still fascinates the public and specialists. The reader who copies the next paragraph and runs it through *Shannonizer* (Senyak, WWW) will easily see why.

Greenberg's tables are something a chemist can fully identify with: the numbers characterise the strength of the bond between morphological atoms, or, metaphorically speaking, of their attraction to each other. In everyday parlance this is what we mean by chemistry—good or bad—of human relations. This is also what we mean by chemistry proper, in which only aggregates of atoms with good attraction are stable and those with repulsion or indifference are ephemeral or non-existent.

The high school chemistry is almost exclusively “good” one. Only when a student goes to a college, he or she discovers that modern chemistry started with the recognition and intense study of structures with bad internal chemistry. They are short-living, rarely observable, capricious, unruly, and cannot be kept in a jar on the shelf, but chemical transformations go through such ghostly chimeras and cannot be explained without them.

This may be an entirely poetic vision, but I associate the **transition states**, as the chimeras are called, with fleeting **thoughts**. Indeed, what is captured and fixed into a stable grammatic form as a generic “thought,” like “All people are born equal,” is only the stable result of the thought **process**. I suspect that thoughts are unobservable for the same reason most chemical transition states are: they are, as the old chemists used to say, *in statu nascendi*, in the moment of birth.

If thought is a **transition state** and the verbal output is the **final state**, the inavoidable question is what the **initial state** of thought is. Questions of this kind, comprising the entire triad **source—thought—language**, have been generating the Himalayas of literature through millennia. I would prefer to leave the majestic background behind the merciful fog and present the larger picture as a few snapshots taken through a chemical lens. As language is a linearization of an image and image is a projection of an object, my notes are only a projection of both into the mind of a chemist, extruded as a text output, not without the help of a computer.

The main para-linguistic problem that arises in connection with matrices and tables is how to send the entire Greenberg table over the telephone. Same problem exists in chemistry: how to send a structure over the telephone? Without the Internet, of course.

5. CHINESE AND CHEMICLESE

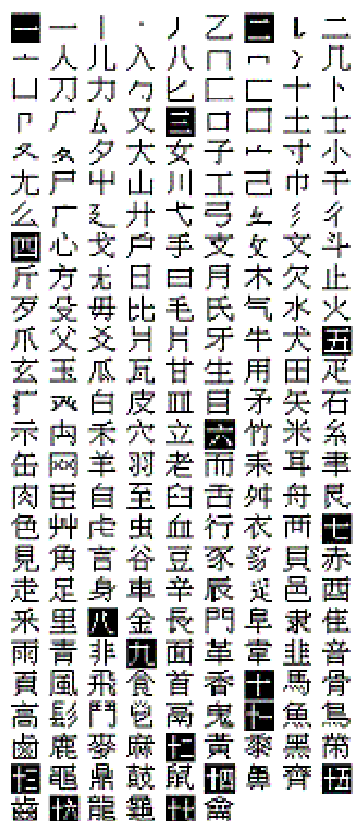
I believe that an organic chemist thinks not in words but in structures. They form the sustaining environment for the chemist, like the animals for the hunter or the plants for the gatherer on the verge of a protolanguage. I definitely see structural formulas or their fragments when I think about familiar compounds. They are the **source** of my **thoughts** about them and they can be shared.

Some of chemical thoughts are visual images of relatively simple structures, like benzene, while others are more complex but seen in all details, especially if the chemist works with them daily. Chemists can mentally operate the structures, similarly to the blindfolded chess player who can remember and operate positions on the board. For chemists, the relation between the object and its representation is exceptionally straightforward, **iconic** (Peirce, 1992).

The development of a separate language in chemistry by the end of the nineteenth century, when the first comprehensive handbook appeared, was driven not so much by the need to communicate with other chemists, which could be better done on paper or blackboard, but, as I believe, from the need to store and search the stressfully mushrooming literature. A similar problem arose millennia ago in China.

The Chinese characters (*Kangxi* in China and *Kanzi* in Japan) consist of standard elements arranged in a certain order. They come from ancient pictograms, later combined into ideograms and supplied by phonetic elements.

Radicals

Figure 5.1 Chinese *bushou*

The problem with pictograms and ideograms is that there is no preferred or obvious way to order a very large number of them. In China the stress that such situation inflicted on the business of making dictionaries was resolved around 140 AD by using components called radicals (*bushou*) as “quasi-alphabetic” and partially semantic markers, while arranging them in order of increasing number of brush strokes (a combination of right and down strokes is considered a single stroke). Figure 5.1 (from Zhongwen, WWW) shows the Chinese *bushou* counterpart of alphabet. The white-on-black characters are Chinese numerals from 1 to 17 signifying the number of strokes. The modern system of 214 *bushou* radicals was introduced in the seventeenth century. The Japanese writing system uses the Chinese characters, limited in number by the script reform of 1946 to 1850 characters (now 1942), but is significantly different as a whole because of a separate indigenous phonetic system,

not to mention the grammar.

Figure 5.2 shows a smaller part of all ideograms with the radical 人, person (top left-hand corner), which is used also as a whole character. As a radical, it takes different forms depending on left or top position. The arrows point to: 1. Feelings (two + person). 2. Partner (person + fire, i.e., at the same fire). 3. Position (person + standing).

The chemical nomenclature, amazingly, uses the same principles of dividing the structures into classes by semantic features, and arranging them within the class by their components and size (IUPAC, 1993). Examples are the radical “person” in Chinese and the class “heterocycle” in chemistry, i.e., cycles built with participation of atoms other

than carbon. If there is more than one cycle, the compounds are ordered in search systems according to the number of cycles, their size, number of non-carbon atoms, and their types, which is all much more complex than the Chinese characters.

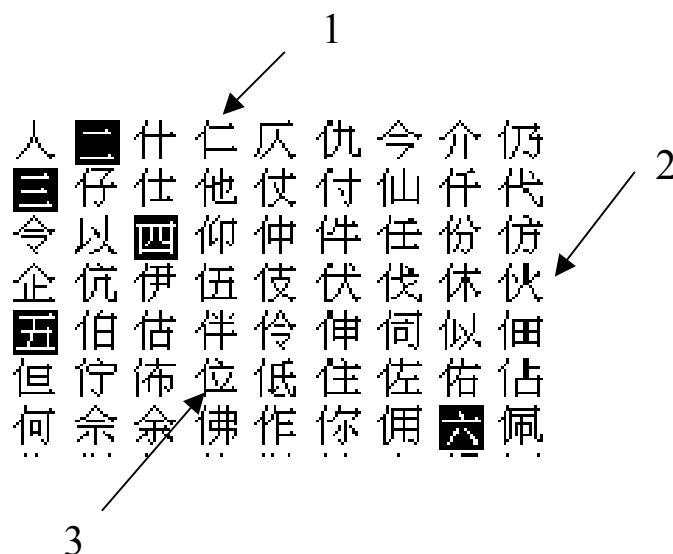


Figure 5.2. Some Chinese characters with the radical **ren**. Inverted characters indicate the number of additional strokes. Explanation of arrows, see text.

Like Kangxi, chemistry uses numerous abbreviations and shortcuts. Now and then, both Chinese characters and nomenclature are ambiguous or just difficult for a novice. For a curious example, see Appendix, 1.

The chemical notation allows multiple versions of portraying the same structure, which can be transformed into each other by simple operations,

such as permutation, flipping, stretching, rotation, etc. What remains invariant is the topology of the molecule. It can be represented by a molecular matrix, for example, in the

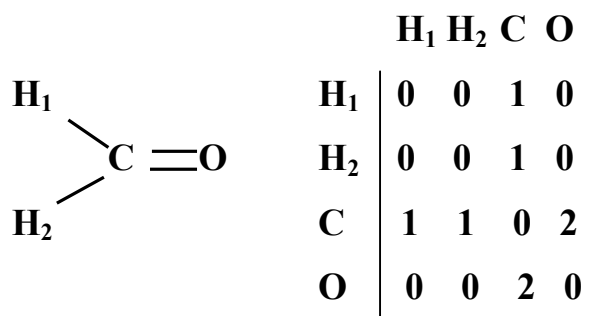


Figure 5.3 Formaldehyde and its molecular matrix

case of formaldehyde with indexed hydrogen atoms, Figure 5.3.

Since the hydrogen atoms in formaldehyde are indistinguishable, the indexes are redundant, which is generally not the case, for example, in methanol with two types of hydrogen atoms, Figure 5.4.

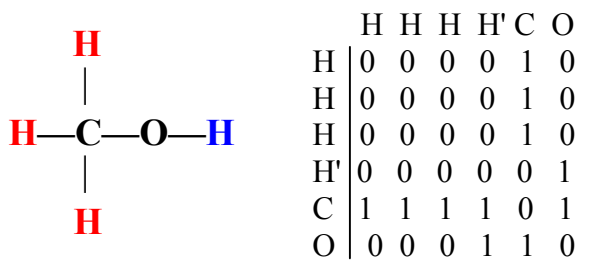


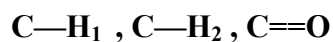
Figure 5.4 Methanol and its matrix

The nonlinear pictographic and ideographic character of Chinese and chemical nomenclature separates the sound from the sign. Both systems of language make the message visually understandable, respectively, for all chemists regardless of language

and all literate Chinese speakers regardless of very significant dialect differences. The spoken foreign Chemicalese, however, can be incomprehensible even for a chemist. Thus, in Russian, “benzin” means gasoline, while benzene is called “benzol” (from German).

The musical notation can also be viewed as a quasi-hieroglyphic system where the signs represent the sound and its duration by separate means. But the notes clearly display a property that is much less pronounced in other languages: music, like natural speech in real circumstances, is mostly continuous and it consists of a hierarchy of overlapping segments, including very large ones (unless it is minimalist). For music as language, see Jackendoff (1987, Chapter 11).

The matrix representation of chemical structure is not something that could be found in a textbook: the chemists do not need it, unless they are developing chemical software. The following is yet another representation of the structure of formaldehyde, I believe, not to be found anywhere, although the principle is known in programming as sparse matrix.

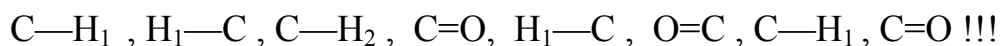


This representation lists the pairs of connected atoms in no particular order and contains the same information as structural and matrix representations. All three can be reconstructed from each other.

The list (sparse matrix) for methanol is: 3 (C—H'), C—O, O—H'.

What neither the matrix nor the list have is *iconicity* (Peirce, 1992), a similarity to the molecule itself. Note that similarity is a cardinal notion in Pattern Theory and can be formulated in exact terms. What the list has, however, is linearity and spontaneity. The

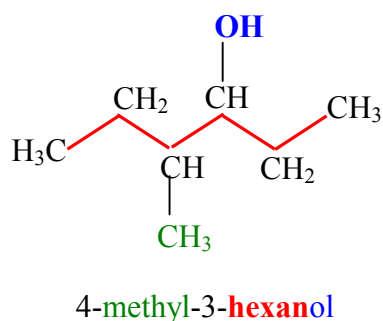
latter means a relatively high entropy and **low effort** resulting from a minimum of rules required to assemble the list. The list of binary connections is, paradoxically, a random way to represent order. From a sufficiently long random list with repetitions and reversals of the doublets ($C-H_1 \leftrightarrow H_1-C$) a complete representation can be easily derived by eliminating redundancy. Thus, the list like this:



reminds a fresh on the spot account of a witness of a horrible accident to a policeman. The agitated witness is repeating and varying the same phrases while the policeman is jotting some concise notes down. The excitement of the witness creates an internal noise and repetition is a patented way to get the information through a noisy channel.

Our cave-dwelling ancestors are unreasonably portrayed in the movies as unkempt and dirty, which can hardly be seen even among monkeys, but we definitely could not expect from them the eloquence of Demosthenes. The eloquence of a survivor of a plane crash is more probable—the crash of old good animal life.

The most important thing for us is that a highly randomized linear sequence of pairs is sufficient to code a non-linear chemical formula. To preserve the binary relations in whatsoever order is all that is needed. To think in Pavlovian binary relations “ringing”—“food” is something any mammal is good at.



The language of chemical nomenclature linearizes the formula of the substance on the left by deriving its name from the longest six-carbon chain, here hexan, C_6 . The atoms of the chain are numbered and the groups that substitute for atoms of hydrogen are listed by their “morphemes” *methyl* and *ol* in a prescribed order along with their

positions. The components of carbon chains, such as methyl, are called radicals, while *ol* is an example of a function (hydroxyl). It is more complicated if the substance

contains cycles and non-carbon atoms in long chains. Chemical nomenclature widely uses parentheses and brackets as syntactic means of grouping, nesting, and long-range connections.

Both written Chinese sentence and chemical name are perfectly linear in appearance. There is as little similarity between a structure and its chemical name as between a live person and the sound **ren** that signifies it, but the structure can be reconstructed from the name. **The chemical name is a linearized molecular matrix.** The Chemicalese does it by using the complicated grammar of chemical nomenclature. This is the simplest universal grammar, truly minimalist, and seen in all its nakedness. Still, it does not say anything about protolanguage.

In spite of my declaration that chemists think in structures, the chemical thought is not observable, either. A chemist may associate with the word “formaldehyde” its gross formula CH_2O , structural formula, the image of the bottle, or the smell, depending on context and circumstances. In a discourse, ambiguity, never completely suppressed, is minimal or easily resolvable by a question.

The chemist has all the reasons to believe that the chemical formula is not just a symbolic representation of the molecule but its model or a projection of a model that preserves important properties of the original, namely, its topology and in some cases its metrics. What the chemist keeps in his mind—and the formal linguist brushes off—are the physical properties of atoms and “atoms” and bonds between them.

To summarize, the function of language, so clearly demonstrated by chemical nomenclature, is first and foremost linearization. It turns the **source** (configuration, event, situation) into a string. In the rather rare chemical case, the source, **most probably** (but you never know), differs very little from its invisible mental representation.

The natural for a chemist idea that **the haphazard list of bonds as relates to the rules of chemical nomenclature as protolanguage relates to language** is the central proposition of this paper. There have been currents in linguistics, as well as in the collective painting of a larger picture, flowing in the same direction and branching into a wide delta.

Atoms are real, so are Og, Ug, cave, and a piece of meat, bur what is verb? Can we put a chemical finger on **give** or **take**?

6. RENÉ THOM AND IMAGES OF CHANGE

The approach to the language through the main entrance from the Broadway of reality counts solid and eloquent literature, including Charles Sanders Peirce (1839-1914; Peirce, 1992), Lakoff and Johnson (1980), Johnson (1987), Harnad (1990), Cangelosi *et al* in Cangelosi and Parisi (2002). Fodor (1976) developed an essentially structuralist approach to thought without the interface with observability, which is legitimate, but his Mentalese is not spoken here because it is not audible.

The entire topic of the interface between reality and the mind is so heavily burdened by centuries of philosophic discussions, starting from Plato's cave, that it is best not be touched by a chemist. But the topic is alive and exciting, especially, in view of some recent postmodernist attempts—uncharacteristically serious—to unite sciences and humanities. See for example, De Landa (1998).

The opportunity to bridge the “embodiment” linguistics, generative linguistics, and natural sciences was missed when the René Thom published his *Structural Stability and Morphogenesis* in 1972 (Thom, 1975). He refers (Thom, 1975, p. 116) to

generative grammar and draws a parallel between linguistics and biology, both having a hierarchy of morphological levels.

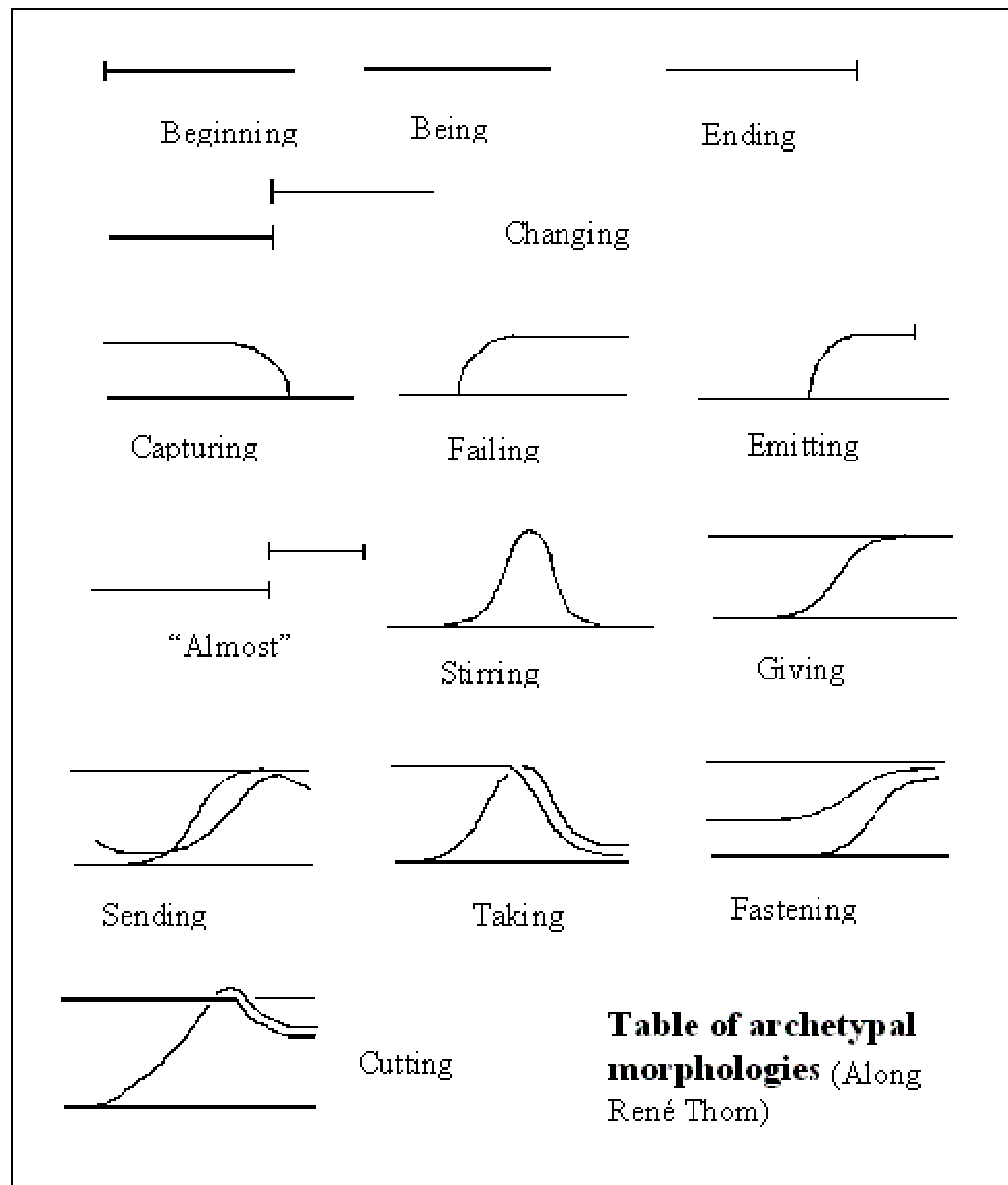


Figure 6.1 Archetypal morphologies of René Thom

The name of Rene Thom (1923-2002) is practically absent from linguistic literature. He was a French mathematician who presented a very general theory and typology of sharp **discontinuous** changes in the evolution of forms. His book was enthusiastically received but rather quickly set aside, probably, as Thom noted, because it did not lead to anything calculable. Besides, it was sometimes easier to see his intent than to follow his thought. Sadly, Thom is fading from scientific memory even faster than Zipf who remains at least anchored there by Zipf law and his “eccentricity.”

David Lightfoot comes closer than anybody to the concept of transition state in linguistics. He mentions Thom in his detailed and hands-on linguistic book (Lightfoot, 1999), which is unique in its thorough attention to the science of complexity, the exactness of the large picture, and the metaphoric power.

Figure 6.1 illustrates Thom’s typology of “catastrophic,” i.e., abrupt changes. Note, that almost each of them carries a name of a verb, including **give**. In my chemical interpretation, Thom distinguishes between three stages: stable and prolonged initial and final states, not pinpointed on the time axis, and a short transition between them.

Thom’s types may seem nothing but modern ideograms that could be used in an artificial script similar to Chinese. The cave pictures of the hunt, where some animals are chased and other are lying dead or wounded, are, probably, the first pictograms of verbs right at the fork road where language is about to split from art.

The minimalist ideograms of Thom can be compared with some of those suggested by linguists, Figure 6.2.

The *image schemata* of Mark Johnson and George Lakoff (Lakoff and Johnson, 1980, Johnson, 1987) are less abstract than the archetypes of Thom. While the latter clearly distinguish between the tree diachronic stages of any change, the former appear to be just ideograms, like the Chinese characters in Figure 6.3.

Thom’s “chreods” capture an important property of transition dynamics and possess some iconicity, while the static characters are purely symbolic and are interchangeable. According to Thom, chreod (“necessary path,” the term borrowed from Waddington, 1957) is a stable configuration separated from another configuration by a catastrophic change.

Let us put ourselves in the position of the first humans who have few abstract ideas. They see a piece of meat in the hands of Ug. After a while it goes to the hands of Og. Having witnessed this process, how can we communicate it, for example, as gossip (Dunbar, 1996/98)?

What is the machinery of language trying to accomplish? The system appears to have been put together to encode prepositional information—who did what to whom, what is true of what, when, where, and why—into a signal that can be conveyed from one person to another (Pinker, 2003, p. 27).

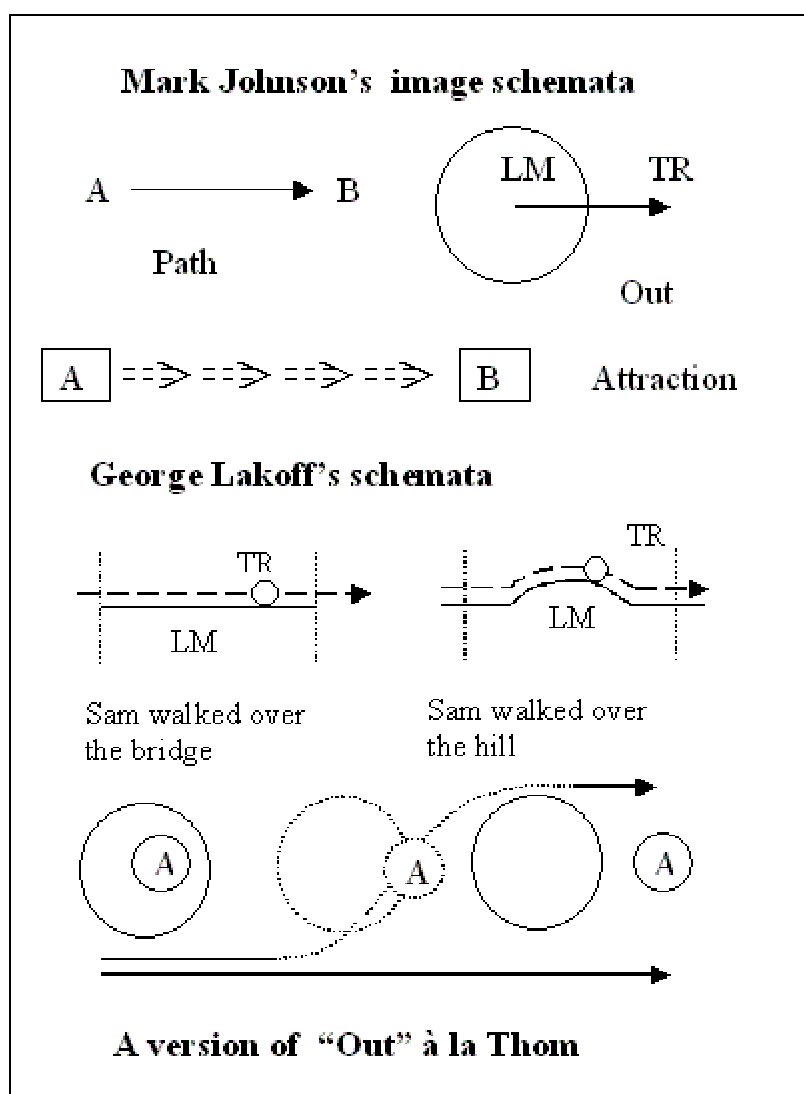


Figure 6.2 Some modern ideograms

In the primitive life who does what to whom and what the alternatives are is of an utmost importance.

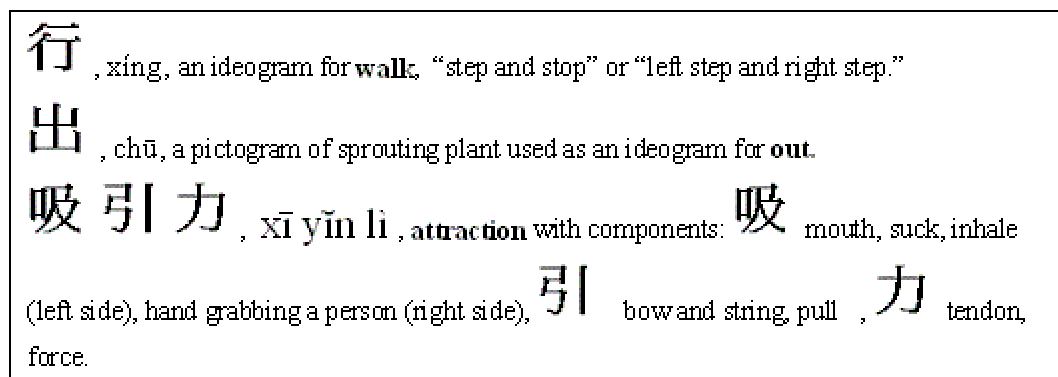


Figure 6.3 Ideographic composition in Chinese writing

Among the enormous variety of attempts to represent graphically what I call external sources of subsequent thoughts, semantic networks (Quillian, 1968) have been the oldest approach in Artificial Intelligence. The arbitrariness of knowledge representation, which reminds to a chemist a relative arbitrariness of writing 2D formulas of 3D molecules, is the reason for the never-ending flow of such graphs. Here is another example.

Cornelis Hoede (Hoede, 2003) and his group build very attractive knowledge graphs as, for example:



The square, called token, is “something” identified (EQU) as PLUTO and similar to DOG: “something like a dog equal to Pluto”

The number of binary relation types is limited to eight:

EQU : Identity
 SUB : Inclusional part-ofness
 ALI : A likeness
 DIS : Disparateness

CAU : Causality
 ORD : Ordering
 PAR : Attribution
 SKO : Informational dependency

And yet the simple “Mary and Mike married” requires four tokens and nine relations for representation, Figure 6.4.

Example: Mary and Mike married.

Graph:

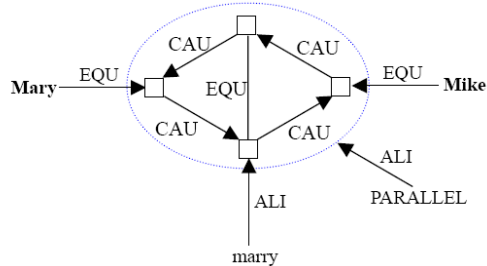


Figure 6.4 Example of knowledge representation. From Hoede (2003)

Sowa (2000) provides an excellent guide in this world created by the drive to overcome the suffocating linearity of our language. We see in the postmodern art a similar drive to overcome, in the form of an installation, the Euclidian restrictions on the tangible classical form and its synchronicity. On the contrary, language itself started with overcoming the overwhelming connectedness of the world and passing it through the bottleneck of speech in segments.

The obsession with graphs, shared by chemists, has an underlying agenda in linguistics: to penetrate into the structure of thought. If we take up the vow of abstention from painting the images of thought, the graphs like those in this chapter fall in the category of **images**, which is a term of Pattern Theory. Image is the **observable** configuration generated by the object in the sensory anteroom of an organism, robot, or by an imaging instrument. The actual configuration of the object, which I call here the source, can be to some extent reconstructed from images, as it is done in CAT scans, Mars rovers, or the intelligence reports based on numerous and only partly reliable sources. The chemists do it from instrumental and analytical data.

Speaking half-metaphorically, if it is about medicine, in the **image area** between the source and the thought, the skeleton of the source is cleaned from flesh and prepared to be taken apart and arranged as a lineup of bones for transportation, as an unearthed skeleton of a dinosaur, but this is all we can say about it. Thus, a series of CAT scan

images results in the verbal linear description and diagnosis (intelligence report), with most of the computerized flesh retired to the archive or discarded.

The process of protolanguage generation, from the point of view of a chemist, displays between the external source and the output, passing the stage of **image** (projection of the source), **thought** (invisible), and **speech** (observable):

Source $\rightarrow$ image $\rightarrow$ thought $\rightarrow$ output

The mathematical language of Pattern Theory is the *lingua franca* for all three stages. PT also offers its own approach to configurations in the mind.

The General Mind Model (GOLEM) was suggested by Ulf Grenander (2003) as a natural application of Pattern Theory (Grenander 1976-1995) to systems of high complexity

The internal output of GOLEM, which is a state of GOLEM's mind, is a configuration called *idea*. It consists of atomic generators connected in a certain order, is limited in size, and is preceded and followed in time by other ideas. The idea can be spontaneous or induced by an external stimulus. It is selected along a probability distribution for generators and their connections.

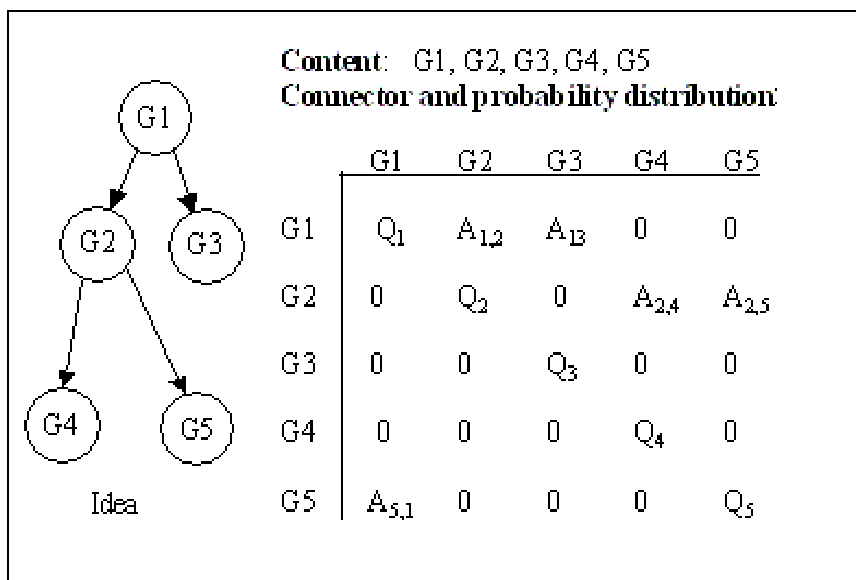


Figure 6.5 . Configuration of an idea, along Grenander (2003), modified

Figure 6.5, modified from Grenander (2003) shows a typical idea of GOLEM in a matrix form. It is a list of all generators in the **content** of the idea, together with the **connector** graph. We can expect, that in a further evolution of GOLEM, this representation will persist.

The nature of generators here is irrelevant. They can be physical objects, ideas, emotions, memories, instincts, and all atomic components of a *state* of the system, in accordance with the *compositional* principle of PT. In linguistics, the generators are words or their roots, no other question asked.

The probability distributions Q and A , from which the idea is stochastically selected, are calculated from the previous Q and A , as well as from the external input, and are subjected to dissipation in the form of forgetting. GOLEM's mind, therefore, is a thermodynamically open system. While Q gives the probabilities of generators for content selection, A gives the acceptor functions (affinities of generators toward each other) from which the probabilities of bond couples in the connector are calculated.

GOLEM's **idea**, therefore, is a quartet $\langle \text{CONTENT}, \text{CONNECTOR}, A, Q \rangle$. In the case of mental activity, probability distribution Q , in very general terms, can be compared with the priorities of an agenda: some items are more urgent than others. To use another metaphor, the state of mind is a pandemonium of generators, most of which are silent, and some of those few that are heard are louder than others. Accordingly, A reflects the strength of the bonds between generators and, therefore, the relevance and consistency of the content.

In the current Version 3.1 of GOLEM the output is a graph. Its internal precursor is **connector** in the form of a sparse matrix of the connector graph, which is essentially the list of bond couples between the generators selected into the **content**. It reflects the content and topology of the idea but its interpretation can be confusing for generators of high arity, as well as for fragmentary ideas. This confusion, however, is an intrinsic property of thought before it has been verbalized. While all the other known to me graphic approaches to thought aim at expurgating any ambiguity, Grenander's GOLEM proudly carries the poster: TO ERR IS HUMAN.

7. CONFIGURATIONS, PATTERNS, AND NEAN

The key to the evolution of protolanguage, language, society, and life itself is lost in an unobservable past. All we can say is that evolution starts with something extremely simple and accumulates complexity by simple steps.

In this chapter, pursuing the large picture, I am going to pass over the insurmountable stack of literature on evolution. I will firmly hold onto my chemical intuition and experience, as well as the major ideas of Pattern Theory, which for me has been a meta-chemistry. Along the way, the simplest and a simple, but not the simplest, mini-grammars for protolanguage will be described in a few lines.

Pattern Theory (PT) is a branch of mathematics that embodies a very **simple** and known since Democritus and his proponent Lucretius (1958) principle of generating **complexity**: complex structures are produced by **combining** simple elements.

Within the framework of PT (Grenander 1976-1995), both molecules and expressions, whether verbal, written, or pictorial, are **configurations** made of atom-like primitives, called **generators**, with potential **bonds** capable of locking into actual **bond couples**. Each generator possesses a certain bond structure (number, label, orientation, sometimes, spatial order, and numerical properties) which in chemistry is usually associated with valences.

Since all differences between complex objects can be expressed in terms of elementary blocks and a particular order of their connections, PT is an incomplete but extremely general and powerful view of the world, especially outside the domain of

physics. It is a platform on which a more complete view of a great diversity of discrete and discontinuous objects can be built by adding other mathematical tools. The generative grammar, in which expressions are various combinations of various blocks, falls into the application basket of PT together with chemistry and countless other areas.

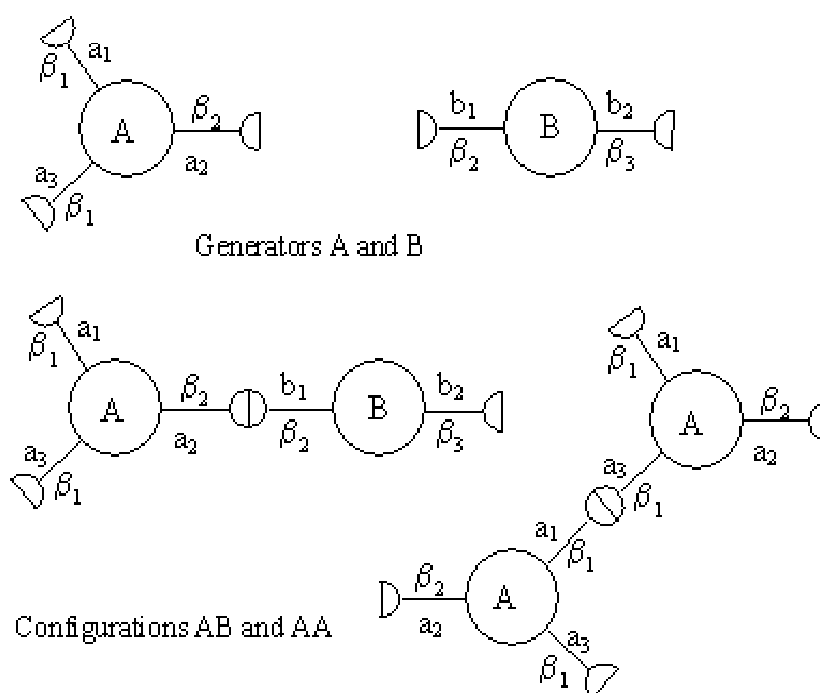


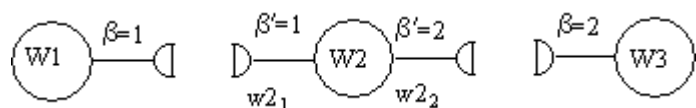
Figure 7.1 Generators and configurations

As an example, two generators from a **global** generator space **G** are identified as **A** and **B** in Figure 7.1. They have bond structures characterized by **local** bond coordinates **a** and **b** indexed both individually and by their generator. For example, bonds of generator **B** are indexed as **b**₁ and **b**₂. Bond values **β** (numerical, Boolean, or strings of characters) are attributed to the bonds. Given the generator space and a bond value relation ρ , a configuration space can be defined so that for each pair of bonds with values β and β' , bond value relation ρ is either TRUE—and bonding is allowed—or FALSE—and bonding is forbidden. A configuration built “by the rules” is *regular*.

Appendix 2 presents some large real-life configurations that can make you speechless.

The realism and power of PT comes from its flexibility. All the rules can be relaxed or made stricter. Thus, the bond value relation ρ can be characterized by a real number between 0 and 1, which is neither TRUE nor FALSE, but just a probability of the bond. For example, the Greenberg tables—the example I will exploit *ad nauseam*—describe a space of regular bonds between the letters of the Arabic roots in various positions. They also fuzzily divide the entire space of possible letter doublets into regular and irregular. Thus, two identical letters in positions I and II are highly irregular.

The regular Arabic roots are triplets of consonants. This **pattern** is defined on the following generator space ($w2_1$ and $w2_2$ are bond coordinates of generator W2):



The regular configurations are those for which $\rho = \text{TRUE}$ if $\beta = \beta'$, which gives the single possible configuration W1-W2-W3:



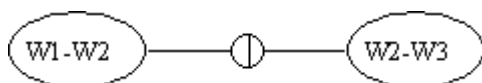
This configuration is, in fact, a pattern, i.e., a class of configurations that can be obtained one from another through the same **similarity transformation**, in this case, **permutation** of consonants. It means that W1, W2, and W3 are not individual consonants, but the entire consonant alphabets. To push this idea to its limits, the combinatorial machine that Gulliver saw in Laputa, is nothing but a pattern of all possible strings of text, generated by permutation of letters.

This property of combinatorial systems is characterized in practically all general courses of linguistics as combinatorial infinity. In PT—as well as in chemistry—the “infinity” could be drastically cut by the properties of generators, as it is the case in

Semitic verb roots. Out of $29^3 = 24389$ possible triplets, only 3775 roots (15.5%) were listed in the source dictionary. The probabilities of the consonant pairs significantly differ.

The Greenberg tables describe an artificial object: the list of all Arabic verb roots. They have nothing to do with any actual conversation or text, in which only a small part of them could be used. The power of the approach is that the statistics of the list of verb roots is similar to a DNA analysis: it can be used for the kinship analysis between Semitic languages and dialects, both synchronically and diachronically.

From letters we switch to words, where a peculiar situation arises. Two-word generators (W1—W2) and (W2—W3) offer a natural choice of bond values identical with the constituent words. For bond relation $\rho = \text{TRUE}$ if $\beta = \beta'$, the following doublet of composite generators is regular:



It directly translates into W1—W2—W2—W3, which turns into a triplet if the rule of **haplology** is applied. Haplology was in the focus of Zipf's theory of the least effort.

Witness the phenomenon called haplology; when two similar syllables—they need not be identical—are adjacent, one may become permanently truncated. (Zipf, 1965, p.85)
Abbreviation is then actually a short-cut; and moreover, since the stream of speech knows no other arrangement than that of time, *an abbreviation of speech is a short-cut in time* (ibid., p 284) .

Haplology—the word itself is ripe for haplology—results in two identical neighbors rewritten as one:

$$W1—W2—W2—W3 \rightarrow W1—W2—W3$$

If we are not in the mood for hairsplitting, this **single rewriting rule** already constitutes the smallest transformational **mini-grammar**. Unlike a grammar of a full

language, this grammar is strictly local and does not require any extended memory for generating an output. The speaker does not need to keep a large part of the entire image of the source in mind to express the thought, as it might be required for using a German verb with a separable prefix or for expressing a complex thought in any language. Only a recognition of two adjacent generators as different or identical is required, which is an effortless task for human mind and, probably, a foundation of all animal intelligence.

Clearly, there is an even simpler grammar, used by animals, in which the configuration is a single isolated generator, i.e., a sign, but this is no grammar at all, but a naked lexicon.

The first step in the evolution of grammar is the language with utterances connecting two generators.

A slogan in knowledge graph theory is that “Thinking is linking somethings” (*Sic!*).

Hoede (2003).

I call this language **Nean**, as a tribute to our cave-dwelling ancestors. I do not mean that the Neanderthals really spoke it.

To start with a binary relation is the most natural thing for a mathematician. The idea that protolanguage starts with a pair of connected words was convincingly discussed by mathematician Keith Devlin in his remarkable book (Devlin, 2000). He even gave a formal Chomskian structure for it as an elementary tree with unlabeled nodes (p.170):



This idea is completely in line with the general concept of protolanguage by Bickerton (1990, 1995, 2003), who had created the entire area, previously avoided by linguists, and whose work had an impact on Devlin (as well as on myself, of course). On my part, starting with Bickerton’s idea, I am also strongly influenced by Pattern Theory and the concept of configuration in which both generators and bond couples contribute to stability. What I consider the main product of this influence is the assumption that Nean

is capable of expressing much more than a simple link: it expresses a source up to a significant complexity.

Nean directly translates binary links in the source into doublets in the utterance. Nean looks like a sequence of doublets. Of course, it can be peppered with singlets. A conversation on Nean looks like:

“ab a b a bd ad d d ad !”

“d d d ab c ab c!”

Or:

“Ug big big big Ug big Ug .”

“Og Og hungry Og hungry hungry”

Nean may require some phonological means to mark word delimiters and stops, but the Ug-Og dialogue shows that it is not absolutely necessary. The change of content or a natural pause caused by an external event would do.

I claim, without any proof, that this is where the human language starts. A dog can say “I am hungry” or “I want to go for a walk” by whining at the table or sitting at the door because the dog’s “I” is clear from the context. Probably, literature on animal communication can provide more complex messages, but I am not familiar with it.

On the example of this primitive grammar we can see the distinction between the formal grammar, in which an unlimited number of generators can be combined in a doublet, and the actual utterance generation, in which the output is dictated by the source. For a formal linguist, any doublet is as good as any other, while for the linguist who looks at the language generation as natural process, only the doublet that preserves the connectivity of the source is good, and the one that does it best **is** the best. We have a parameter for comparison—called *fitness* in Artificial Life—which is a condition of “naturalness” in terms of thermodynamics as well as **selection**.

To make the next step and launch the evolution of grammar, we take a random sequence of doublets and compress (“zipf”) it, using the following set of rewriting rules:

$ab + bd \rightarrow abd$

$ab + ad \rightarrow abd \text{ OR } adb$

$ac + bc \rightarrow abc \text{ OR } bac$

This “haploid Nean” is an example of a mini-grammar of a somewhat larger size.

Given the list of generators from generators space $\mathbf{G}$, the probability of a configuration is defined by the probability of its bond couples. Instead of products of probabilities, sums of logarithms of probabilities (“energies”) can be used, which makes a configuration additive regarding the “energies” of its bond couples, as it is typical for chemistry. The “energy” is a quantitative measure of what can be approximately characterized as the strength of the bond couple or the mutual affinity of two generators.

A series of mathematical and practical problems arise when we apply the concepts of probabilities and energies to non-physical systems such as language. I am not qualified to analyze this aspect of theory and can only outline the essence of the difficulty as well as a way out.

To use probabilities, we need a complete system of possible outcomes in a dynamic system, as well as a clear criterion of which outcomes are independent. This is a very tall order.

Dynamic systems are ensembles of large number of entities that randomly exchange a certain additive (conservative) value, statistically distributed over the entities. In general, probability and energy are convertible currencies in closed (i.e., non-existent in reality) dynamic systems: the lower the energy of the state of the system, the higher its probability. The lower the overall energy, the more stable the configuration.

This relation, completely transparent in statistical mechanics, which deals with idealized closed systems, is not so clear when we deal with real complex systems.

To use energy, we need a scale with a zero point (or the so-called partition function in statistical mechanics). We meet neither condition in the chemistry of even slightly complex molecules. When we discuss **evolving** systems of life and Artificial Life (ALife), the physical energy becomes meaningless. Instead, entropy multiplied by

statistical temperature could be used—if only we had really well-defined dynamical systems, which we have not.

The problem described here is very general. Probability theory is one of a few areas of mathematics where we can find debating sides (another is—no wonder—the foundations of mathematics). **Bayesian theory**, which is the subject of many sites on the Web and can be found in any, even low-level, course of probabilities, points to the way out of the incompleteness of our knowledge about real systems, which we can complement by additional observable data. An avalanche of works has been triggered by the community of the worshippers of Reverend Thomas Bayes (1702-1761), but it safely passed over the unsuspecting chemists.

In chemistry, the problem of the incompleteness of the data finds a very simple solution. Let us assume that only two structures in equilibrium are of interest, while the rest of the system remains the same. In this case the theory gives us not the absolute values of probabilities of two states, but their relative probabilities in equilibrium, and this is all we need for most practical purposes. The logarithm of the ratio of the probabilities is proportional to the difference of their energies. In general, when we do not know all possible alternatives, let us take only two. We can tell which one is more probable by comparing their energies, provided the rest of the circumstances the same. Equilibrium and evolution of a complex natural system, however, are two incompatible things.

From somebody with a chemical frame of mind, like myself, looking outside chemistry, Pattern Theory offers a general solution for any process: let us judge configurations by their regularity. Irregular configurations are strained, stressed, unstable, and short-living. The regular ones are stable, normal, uncontroversial, legitimate, and dominating. But what is irregular? It is what bends the rules. And what is regular? What conforms to the rules. Well, what is the origin of the rules? They are taken from the observations. Pattern Theory is an unusual kind of mathematics that restricts the freedom of imagination by the observable reality. There is no standard way to design generators, some models could be better than others, and a lot of human intuition must be involved in a development of an application. One might draw from the contraposition of regular and irregular structures an important conclusion that if a stable structure can transform into

another stable structure, it can do it, by definition, only through an unstable one. This is what chemistry is about. Otherwise all **relatively stable** structures on earth would immediately turn into the **most stable** equilibrium combination of the most stable individual structures and time would stop.

The above peek into PT was extremely limited and superficial. One has to look into the original work to appreciate the richness of the subject. One aspect of PT that I haven't even touched upon is the concept of the pattern as a **group** (in mathematical sense) of transformations that define a geometry of the configuration space. The second aspect is the idea of template, i.e., a representative, "typical" (Aha! Here comes the mysterious "typical") configuration of the pattern. It could be the most valuable treat for cognitive sciences: we all have mental templates for "cat," "dog," and "politics." What are they? The centers of gravity of a pattern.

It will do for my purpose to point to PT as a mathematical higher ground, strangely overlooked, for complex systems from which both linguistics and chemistry could be seen side by side as affectionate sisters.

Much more important, the higher ground of PT allows me to represent both the source and the output of speech generation in the same philosophically neutral mathematical terms: as configurations.

I will return to Nean in Chapter 12.

8. SOME RISKY IDEAS ABOUT MATHEMATICS AND LIFE

I must make here a risky digression—it could be safely skipped by the reader—addressed to all those interested in the big picture, including myself. This digression is intended to once again draw attention of all researchers of complex systems to PT. I venture to express an outsider's opinion (anyway, mathematics is a language, too) on the applicability of mathematics to complex real phenomena.

The fundamental *sine qua non* component of any mathematical system is the **theorem of closure**, which requires the set of terms to be well defined and closed to any uninvited visitor during reasoning. It can be traced back to Aristotle and is a condition of logical thinking. In other words, mathematics is poorly equipped to deal with the notion of **novelty**. Once the world of a mathematical system, i.e., its terms and axioms, has been created, whether in six or 666 days, there could be nothing new under its skies. This is definitely not the case under the skies of the planet Earth, as geological, biological, and social evolution—and anybody's personal life—clearly manifest. This is why mathematics, as well as physics, is not adroit enough to deal with evolution and the open set of terms. Real systems are inherently open to new and unanticipated terms, i.e., **new** generators of PT.

Mathematics, however, would not be mathematics if it failed to design a mathematical system for formalizing something. As it seems to me, the seeds of a mathematical theory of novelty were planted in a very little known segment of Bourbaki's monumental *Elements of Mathematics* about the **scale of sets** (Bourbaki,

1968, p.259), to which I would refer the curious reader. It describes how a **new** set of terms is formed from the **old** one by converting **new** combinations into **old** elements for the **next** combinatory step. It seems tricky, but is in fact simpler than it seems.

As far as Pattern Theory is concerned, its basic sets are remarkably open to novelty. PT is just born to be a mathematical tool of evolution because it can construct and implant **new** generators. It does it the same way the scientists express new and groundbreaking ideas by using the strings of old letters and inventing some new symbols and terms. Moreover, by using the convertible currencies of probability and energy, PT stores in its shed all the necessary tools to model the **realistic** evolution of complex systems. Being capable of distinguishing between what is possible and what is more probable than something else, PT straddles the fence between the camps of Chomsky and Greenberg.

Energy or quasi-energy, fitness, etc., can be considered a particular case of a more general concept of the natural world—**stability**, which is the other side of **regularity**.

In real life some scientists (especially, chemists) deal with differences in energy and others (especially, in computer simulation, economics, and cognitive sciences) deal with conditional probability because those are the **observable** source data.

It must be noted that although chemists freely convert relative energy into probabilities (in the form of equilibrium concentrations) and back, they are always aware of inherent uncertainty whether all possible outcomes are taken to account.

This is not the case in the closed system of three-letter roots, where all combinations are completely countable. The roots of Arabic are examples of linguistic molecules. Greenberg's results can be reformulated in terms of energy or affinity, i.e., attraction of root letters to each other—yet another reason for chemistry and linguistics to listen to the call of the common blood in the lush jungles of complexity. So are the giant molecules of musical compositions with the regularity consistently relaxing through the last two centuries. This is what, probably, keeps the drumbeat of pop in demand. Similarly, the statistics of marriage and divorce, to take a different angle, tell about the strength of marital bond in a social molecule and the position of the equilibrium between its two basic states of association and dissociation.

Big ideas have a curious property of staying unnoticed just because of their large size. Coming to the end of my digression, I do not want to miss an opportunity to point to one such idea. I have nothing to lose by mentioning a remarkable way to circumvent the problem of “physicality,” which cuts a deep chasm between physical sciences and humanities, as well as between real and simulated systems. I realize that it may seem paradoxical and even pervert to both separated sides longing for an embrace.

Suggested quite casually by Prigogine and expressed in a very general form by Rosen (1991, 2001), the idea consists in regarding the physical, closed, and calculable world a particular case of a more general world where the vague, large, complex, hard to catch and itemize systems, like life, are a more general case than any physical model. They do not need an explanation through anything else. In a way, what Robert Rosen heretically suggested was a version of the Copernican revolution: the physical earthly knowledge is a satellite of a larger conceptual body of life sciences and evolutionary ideas in general. The “normal” reductionist angle of vision has been: life, society, and mind exist because there is some physical foundation for them. Robert Rosen reversed this relation: no, physics and chemistry exist because there is life on earth. No wonder, the first step that physics made in explaining life was to declare it impossible because of the improbability of a spontaneous assembly of DNA or RNA (Wigner, 1961).

For more about the scale of sets, chemistry, mind, and some illustrations, see Tarnopolsky (2003).

9. CHEMOLINGUISTRY: A CHIMERA

In this chapter I discuss a very general paradigm which does not seem to follow from any other and is one of the relatively recently discovered foundations of modern chemistry: the **theory of transition state**.

Honestly, a linguist has no need to know any down-to-earth chemistry. I will attempt to present here some almost unknown outside chemistry ideas as chimeras combining the properties of both chemistry and linguistics. Atoms will be labeled as meaningful words but will behave like atoms. We will use such familiar terms as atoms, energy, and even probability, in an intuitive and not in the strict physical and mathematical sense. We will try to find some criteria of checking the configurations for a measurable property. We will try to arrange our atoms into more or less realistic configurations. Coming back to Mark Baker's "*The Atoms of Language*," what if words were indeed atoms? Then both the expressions and their sources were molecules and the way from the latter to the former would go through a transition state, as it happens with molecules.

The term "transition state" is somewhat misleading. As all chemists know, it is not a state but a process. It is the state of flux.

The concept of transition state (Eyring and Polanyi, 1931) is a very general concept of **dynamics**—the science of things in motion. It is used in **kinetics**, the part of

dynamics that studies the speed of the motion, but only if the motion is **discontinuous**, i.e., **catastrophic**, in terms of René Thom. In essence, transition state theory regards is as continuous. Can you imagine that?

Transition state theory (TST), introduced by Eyring and Polanyi ... in 1931 as an early attempt to determine absolute reaction rates, is too often considered the domain of the chemist or chemical physicist. However, the transition state (TS) is actually a general property of dynamical systems which involve an evolution from “reactants” to “products.” Such processes include, but are by no means limited to, the ionization of atoms, the dissociation or re-action of molecules, and even the escape of an asteroid from its orbit (Jaffe et al, 2000).

Surely, any asteroid is a pending disaster.

The theory of transition state elucidates why things happen by explaining why they do not. It postulates that if one stable state of a system can turn into another, there is an ephemeral and unstable transition state between them. Its energy (stress) is higher and, therefore, stability is lower than that of both stable states. It is irregular, unlawful, and cannot be portrayed by common chemical formulas.

The transition state sets a **barrier** on the way of transformation. The lower the barrier, the more probable the transformation. This is why a sheet of paper does not ignite spontaneously and needs a burning match to push it over the barrier. For the same reason explosives can be safely stored and transported: they are protected by the barrier of the transition state on the way to the products of explosion. The detonator jolts the substance over the barrier.

Some general notes on transition state will be included into Chapter 11. Illustrations of mechanisms of chemical transformations, in both chemical and metaphorical terms, are given in Appendix 3.

As an introductory example, let us turn to the splendid collection of stressed life configurations left by Shakespeare. When we speak about a good chemistry between persons, we mean that their relation is stable. The initial relations between Othello and Desdemona have a negligible stress, low energy, as a chemist would say. The malicious energy of Iago initiates the explosive transition like a detonator. The highly stressed

situation dissipates its energy along the way to another stable but unfortunately tragic state. The short-living process, which is the core conflict of the tragedy is what a chemist can associate with transition state. The measurable parameter is stress synonymous with instability.

One may visualize atoms as ping-pong balls with a word on each, including symbols of chemical elements, written with a soft-tip marker. We attribute to them the ability to form bonds of various strength measured by the energy: the lower the energy, the stronger the bond and the more energy is needed to break it. Energy, therefore, is a measure of instability and, on a different scale, of improbability in a dynamical system. We will use also the terms **stress** or **tension** as the opposite of stability: the stressed configurations are those with high energy and low stability.

The words can themselves be labels of real or imaginary objects and events. The theory of meaning is one of the most confusing intellectual areas and we should better avoid definitions, preferring models instead.

Model 1

The model illustrates what a chemist could expect from three atoms labeled as words: **Tom**, **Tim**, and **book**. The name of the transformation is **GIVE**. Its detailed description is: **Tom GIVE[s] book [to] Tim**. We can see the extremely stable **Tom**, **Tim**, and the **book**, but no such thing as “s” or “to.” But what is **GIVE**?

We observe the following states:

1. The initial state: **Tom** in contact with the **book** and **Tim** nearby.
2. The unstable and short transition state of transfer, which is **GIVE**.
3. The final state: **Tim** in contact with the **book** and **Tom** nearby.

Figure 9.1 shows the **GIVE** transformation as a chemist could depict it. It turns out that there are two possible **mechanisms** of the process, for which **A** and **B** are two possible transition states.

Since the initial and final states are relatively stable, the book can be in Tim's or Tom's possession indefinitely. In the act of giving, along mechanism **A**, Tom holds the book and offers it to Tim, who also touches it. For a short while the three atoms are locked in the ephemeral and unstable transition state, which is, in general, reversible. Mechanism **A** corresponds to a smooth continuous transfer. Either Tim or Tom, or both can change their minds concerning the transfer. But they can also fight for the book. Along mechanism **B**, Tom can simply leave the book on the table, after which Tim takes hold of it. The transition state for this version of **GIVE** is just three disconnected atoms.

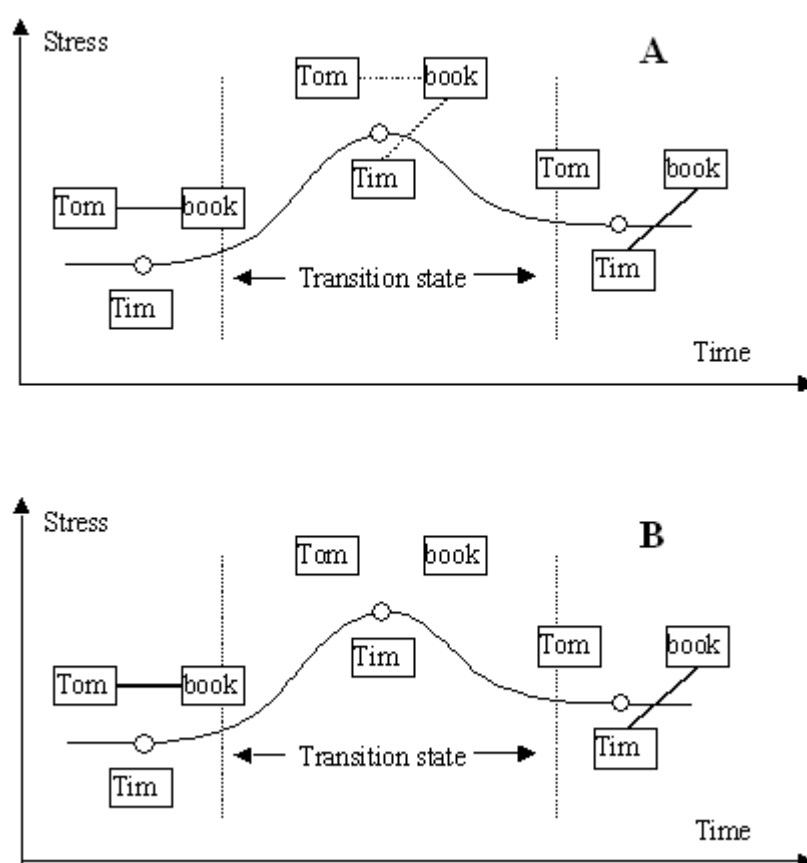


Figure 9.1 Two mechanisms of transformation **GIVE** from the point of view of chemistry.

From the point of view of a chemist, GIVE is a name of a chemical—better to say “chimerical”—reaction between molecules Tom-book and Tim, resulting in the molecules Tom and Tim-book.

How fast this reaction could run depends on the energy (height) of the transition barrier. To chimerize more, we can even say that while Tim and Tom can do well without each other, a book without an owner is an irregular and therefore unstable configuration, while a book with two owners is also a potential source of conflict, unless there is a stable bond between the owners. For the forceful transfer, the transition state can be highly stressed and its outcome hardly predictable unless we know which stable state is less stressed, i.e., who is stronger, Tom or Tim.

The transition state starts with some really invisible processes in Tom’s mind. To make any predictions about the direction and speed of the transformation, we have to evaluate an open set of other circumstances not in the slightest way reflected in Figure 9.1: relation between Tom and Tim, whether Tom has finished reading it, the availability of other books that Tim could use as substitute, the influence of other persons who have their opinion about Tom, Tim, and book, and even if the weather is better for reading than for sailing. This is exactly what a chemist does to study a chemical transformation and optimize its course by increasing the speed of the beneficial transformation and suppressing all the competitive directions.

Catalysis is the standard tool for speeding up one direction of structural change at the expense of the competitive ones. Catalysis can be compared with the role of a parent in a smooth transfer of a book from one child to another: the parent forms bonds with all the participants and decreases the stress of the transition state.

In fact, both types of transition in Figure 9.1 are known in the process of chemical transfer of an atom from one place to another, with some additional considerations. Once again, the transition states in chemistry, like thoughts in the brain, are not typically observable. They are, actually, chimeras of imagination, although some progress has been recently made in catching them. But they leave evidence which is observable and can be identified by the same detective methods as a crime without a witness, including forensic experiments (Appendix 3).

The above chimerical mechanisms are popularizations of what happens during the chemical transformation: it goes through a transition state the energy of which determines **how fast** the transformation will happen in the **short run**. Tim and Tom exist in single copies, but molecules are numerous. In the **long run**, since the passage through the transition barrier is reversible, there will be an equilibrium depending on whether the initial or final state has a lower energy. My illustration is intended to draw attention to the **kinetics** of transformation, i.e., the short-run outcome. Chemistry is interested most of all in the speed of the transformation. If there are more than one direction of a process, chemistry answers the question “what is going to happen when the process starts?” in the typically chemical manner:

In the short run, what happens is what can happen faster,
i.e., what goes through the least stressed transition state, and
in the long run it is the less stressed stable state.

The universality of this principle can be seen on any modern war: it is easy to start but hard to finish.

The aspect of speed (usually called **rate** in chemistry) has attracted little attention of philosophers used to the fleshless creations of the mind where everything that can be put into words is possible and it pops up in all minds with the same speed. Instead, endless debates about body and spirit, form and substance, semantics and syntax, meaning and sign, thought and utterance, all within the static framework of frozen structures, have been rolling through centuries, apparently, without any barriers of any kind.

Why do structural transformations happen at all?

In chemistry all particles naturally follow a distribution of energies (Maxwell distribution), so that most molecules have energy within a medium range. There are always particles with energy above that level and their collisions result in passing the transition barrier.

There is the fundamental thermodynamics of open systems, but no waterproof theory that could predict or explain their design. Examples of open systems are the

atmosphere with weather, life with evolution, society and language with history. It is not clear whether such theory is possible because any general theory would be silent regarding most interesting problems which are always concrete. Moreover, evolution of a large open system is an interplay of chance and necessity. The best way to observe transitions of large complex systems is to read history, which is a roster of long time stagnations interrupted by short term periods of turmoil that not necessarily lead to a new structure, as well as of long term drifts. The Imperial China, Roman Empire, French Revolution, and Industrial Revolution are classical examples. Lightfoot (1999) provided an excellent concise review of this entire area not only for linguists but also for chemists and anybody else who is not shielded from the world by a TV screen.

For a chemilinguist, the development of pidgin and creole languages (Bickerton, 1981) are examples of the resolution of an initial stressful situation of the Babel Tower type. The mass import of West European words into the old Russian language under Peter the Great (the pattern that repeats itself today, so that two alphabets, Latin and Cyrillic, could be used intermittingly), the mass invention of a new lexicon on the base of the old language in China, and the patriotic defense against imported words in Hungary two centuries ago parallel historic processes and are all as much answers to a stress as many scientific shifts and technological inventions. One can only guess whether the theory of punctuated equilibrium in biological evolution is just a spoof of human history.

The notion that an utterance has a short-time history and displays in a discrete time as a mechanism, i.e., a sequence of states (derivations) was to Chomsky's unquestionable credit. But the main revolutionary discovery made by George Zipf (Zipf, 1949, 1965), whose name is conspicuously absent from many recent works on linguistics, even those taking a comprehensive view of the field (from Jackendoff to Uriagereka, for example) was indigestible by static formalism.

If you call something "move," how fast it is? Zipf had no direct measure of effort whatsoever and identified effort with the word length. While Zipf's theory remains controversial, his results are not. A chemist would certainly reformulate the principle of the least effort as the principle of the fastest transformation.

Model 2

In Model 1 only one direction of transformation was possible. Chemical reactions usually run in several possible directions, theoretically, in all of them, which is an incredibly dense branching, fortunately, as implausible as the linguistic “discrete infinity.” Let us take a more ambiguous case of the direct-indirect object tandem: GIVE (ACTOR, RECIPIENT, OBJECT) with several alternatives. It corresponds in English to at least two expressions (excluding a bunch of Passive forms):

1. ACTOR GIVEs an/the OBJECT to-RECIPIENT.
2. ACTOR GIVEs RECIPIENT an/the OBJECT.

The first expression can mean that ACTOR gives to the RECIPIENT one of several available types of OBJECTs, selecting an apple and not a book or a flower. It can also mean (a perilous situation in mythology!) that the ACTOR gives the single available apple to one of several RECIPIENTs. Or, it is one of several ACTORs who GIVEs the only available OBJECT to the only RECIPIENT. It may be a combination of various situations. It may also mean that the object is taken from the ACTOR by force, etc. It can be anything observable by an individual or a group. To reveal the ambiguity in the act, let us analyze the act itself, representing it as a transformation of a configuration, Figure 9.2, where the usual transformation **A** follows by a more complicated situation **B**. We can see a highly uncertain transition state with several outcomes.

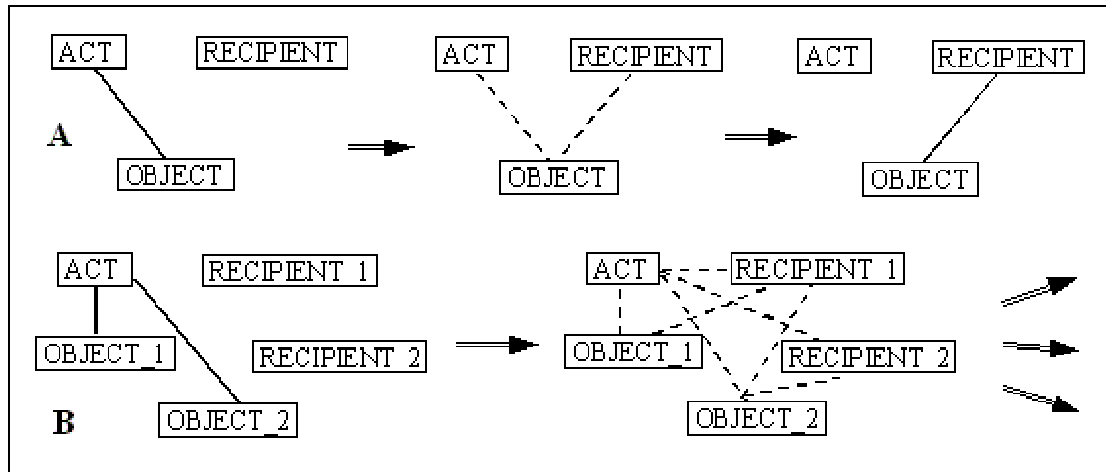


Figure 9.2. Action GIVE represented as configurations

In the initial state of transformation **A**, which can be reversible, the actor is connected to the object. In the final state, there is a bond between the recipient and the object. Between them lies the ephemeral and fleeting transition state in which both actor and recipient retain the connection with the object. The transition state has a higher level of uncertainty than both stable states because the outcome is not known: the transfer of the object can be delayed or cancelled, or the situation can turn into a fight.

We avoid the term entropy, using *uncertainty*, *stress*, *ambiguity*, and *irregularity* instead, because we cannot calculate entropy without a closed set of outcomes and a probability distribution over it, which is so easy in computer models but hardly ever is achievable in real life.

In transformation **B**, where at least two objects and two recipients are involved, the uncertainty is significantly higher and there is a whole array of outcomes regarding who gets what, if any. A web of relations of different *strength* connects the actor and the recipients, so that a combinatorial space of transition states can be described by a matrix of bond strengths between its components. The matrix can be strongly influenced by preceding states and memory traces. The relative affinities of the actor toward the recipients, as well as to objects, may be the decisive factor in choosing one recipient (object) over the other, as it in fact happens beyond mythology.

The outlined picture is consistent with the chemical paradigm, which can be roughly generalized as: the transformation through the least stressed (less ambiguous, uncertain, and irregular) transition state is the most probable one—in the short run.

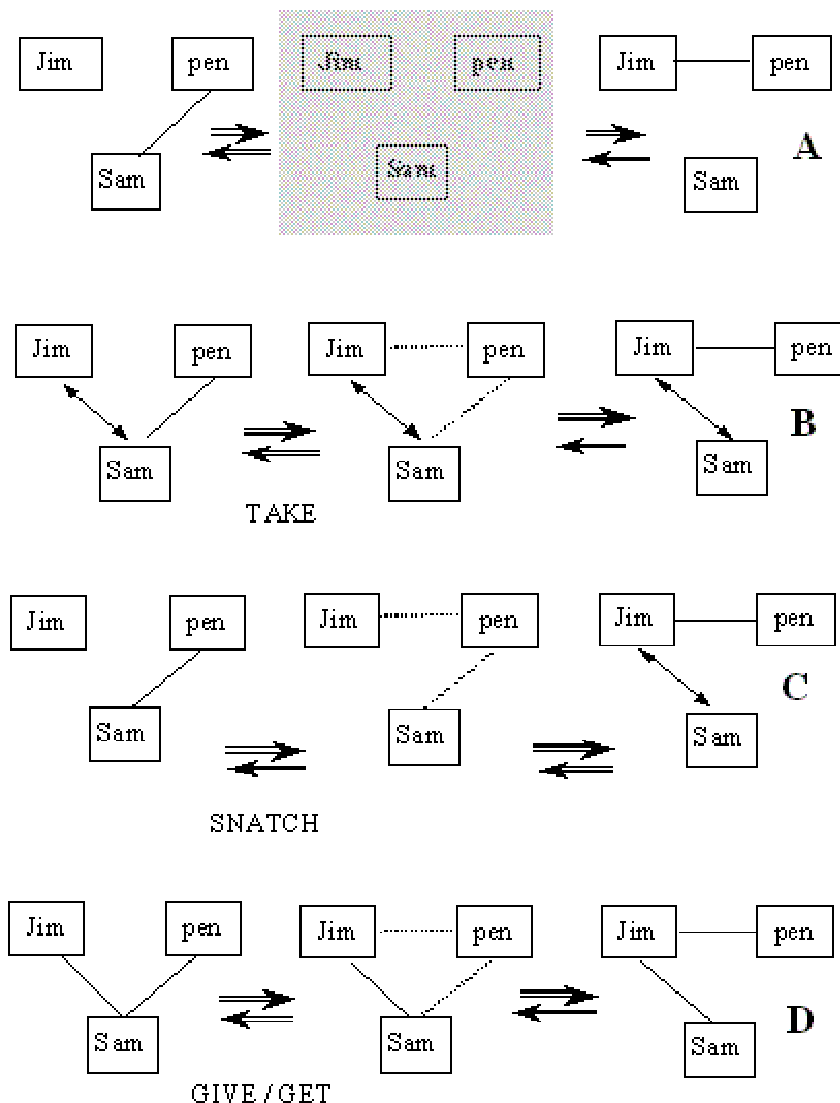


Figure 9.3 Variations of object transfer

The somewhat “thomistic” Figure 9.3 starts with the general situation A of transfer of a pen from Sam to Jim where the exact mechanism of is shielded by the gray square. Transformations B to D reveal a variety of subtleties in the abstract transfer:

- B. Antagonistic relations shown by the two-head arrow suggest a forcible takeover.
- C. Unexpected takeover generates antagonism.
- D. Willful transfer against the background of friendly relations.

These subtleties reveal an important property of the real world: the source can have different images and the configuration of the source can be reliably reconstructed only from the totality of images.

The purpose of my illustrations is to show how the circumstances of an observable event, including the often complicated relations within its human and material participants, influence the outcome. The relations constitute the social framework and they are socially meaningful. We sometimes overlook, as with every big picture, that for some reason, human mind, language, tools, and society had appeared all together and, probably, are just the extrabiological aspects of *Homo sapiens*. If the tools go back to *Homo habilis*, about two million years ago, so may language. The questions of this kind are difficult to answer in any substantial way because the spoken language does not leave a material trace. All we know from observations of ourselves and animal societies is that communication of any kind is a *sine qua non* of social life.

It is not up to a chemist to engage into such discussions. What chemistry demonstrates, if abstracted from the material nature of its generators and bonds, is the fine structure of the transition from one pattern to another. It portrays **a discontinuity as a continuous process** and this is where it goes farther than René Thom.

In the chemistry of reversible transformations, once the system is initialized and brought into motion, the final **equilibrium** is defined in the long term by the energies of the initial and final state, while the short run **process** is defined by the height of the transition barrier. In the chemistry of open systems, to which life, mind, and society belong, the system can be maintained far from equilibrium as long as it is supplied with free energy and can dissipate heat, but in what particular form? In the form to which it has arrived through its preceding historical **odyssey**, with all its trials, errors, accidents and choices, following the beautiful metaphor of David Lightfoot.

The transition states are typical for the open non-equilibrium systems that are searching for a steady state after having been knocked out of the previous steady state. The almost forgotten profound analysis of this phenomenon of **homeostasis** belongs to Walter Ross Ashby, one of the founders of modern artificial intelligence (Ashby, 1960, 1964). The significance of his analysis for the problems of emergent properties comes from the fact that his homeostat was homunculus-sterile and algorithm-free. Regarding language origin, there was nobody to teach protolanguage to the first speakers. Language had to emerge from the spontaneous interplay of configurations in the mind with the configurations of the social life.

There is a deep parallel between a molecular system and the homeostat : the interacting molecules and the blocks of Ashby's machine spontaneously find a state of the lowest energy through a series of short-living transition states of an increased energy. The difference is that in the molecular system the number of blocks is very large. The most important similarity is that each molecule and each block have all the other kinds of blocks in their topological neighborhoods.

10. TIKKI TIKKI TEMBO: LANGUAGE AS A FORM OF LIFE

The molecular matrix is a mathematical object of the same nature as Greenberg's table of Arabic roots. Instead of the number of bonds between pairs of atoms, the distances between them or the bond strength values could be entered. Bond energy is a measure of improbability that the bond will be spontaneously broken. To somewhat vulgarize the chemical reality, the probability of bond breakup is extremely low at room temperature but goes up with temperature or irradiation. This vulgarization is minimal for hydrocarbons, such as the components of mineral oil.

In general, a simple skeletal graph is completely represented by a matrix of incidence consisting of only zeros and ones. Graph **is** the matrix, and its picture is only a visualization. The square matrix, however, can be made as realistic as we want by adding qualitative and quantitative flesh to the bare topological bones and inserting numerical values into the cells of the matrix.

For enthusiasts of long mental leaps, graph as a mathematical object is a beautiful example of an **extralingual language** universal, just look at Appendix 2. If it sounds oxymoronically like "the empty category is not empty," it is only because such terms as language and life each had acquired double meanings after the advent of computer science and molecular biology. There are human language and biological life, but there are also formal languages of programming and mathematics.

As soon as we have a population of interacting configurations, there is a possibility of an Artificial Life system.

In the most general terms, life—it could be called **meta-life**—is a system capable of (1) replicating itself with (2) errors (3) while using a limited resource of energy. The computer that uses the same tiny energy to display any picture on its monitor is an extremely misleading device for those who want to live in the real world. People will not switch from despotism to democracy just because **democracy** and **despotism** are the words of the same length and require the same effort to type them on the keyboard.

It is impossible to review here the modern ideas about life-like systems, and the following remarks will be fragmentary. The major problem with any large picture is that you cannot find a large enough frame to hang it on the wall. You have to reduce it to a size where many important details are just specks. The picture painted by Devlin (2000) is more a window than a picture: it allows you to see the large world through its modest frame with the help of the optical abilities of mathematics.

For the Darwinian biochemical life, duplication and errors (mutations) are obvious, while the limited character of resources of matter and energy are not always kept in mind.

Heat alone cannot be directly utilized by life unless it is processed by power stations and internal-combustion engines and other thermal machines. Only humans have been capable of doing this, albeit only after 1700. This brought to life modern civilization, which is also a form of meta-life. Technology, the most conspicuous part of modernity, uses blueprints and descriptions the same way living cells use DNA for their replication. The limited resources of technology are capital, labor force, matter, energy, and consumption. This line of discourse would certainly detract us from protolanguage and I have to stop here.

There is a trend in linguistics that views language in terms of population dynamics, i.e. as a form of generalized life. For initial references, see Komarova and Nowak (2003), . Similar or related ideas can be found in works of James Hurford, Simon Kirby, Angelo Cangelosi, and others.

Language reproduces itself with mutations within the social communication. But what is its limited resource that exerts a selective pressure? It is not energy, because verbal exchange does not take a lot of energy. I believe, not claiming any originality, that

it is time for both expression and understanding. If communication is too slow and far behind the pace of events, it fails to perform its function and the bottleneck linguistic phenomena die out. The fast development of a distinctive language for wireless text messaging by teenagers is a supporting example.

The situation can be illustrated by the Japanese folk tale *Long Name*, known in USA as the Chinese folk tale *Tikki Tikki Tembo* (Tikki, WWW, A) .

As I remember it from my childhood, the parents gave their boy a very long name to ensure his happy and long life:

Tikki Tikki Tembo No Sarimbo Hari Kari Bushkie Perry Pem Do Hai Kai Pom
Pom Nikki No Meeno Dom Barako.

When the boy fell into a well, the children around started to call his parents but could not chant his name correctly and had to start all over again. While they kept trying, the boy drowned.

NOTE. There was quite a discussion on the Web about whether *Tikki* was a Chinese or a Japanese tale (Tikki, WWW, B). I remember it as a Japanese tale in a Russian translation, and Ariko Kawabata, a participant in the discussion, confirmed it, which does not exclude its Chinese origin.

There are two “biological” approaches to language. One regards language as a classical biological adaptation (Pinker and Bloom, 1990), while the other one is to see it as a form of meta-life (general reviews: Komarova and Nowak, 2003, Hurford, 2003). The second trend opens the Pandora box of computer simulations, but the approaches do not conflict.

I believe it is appropriate to refer here to Cavalli-Sforza (2000) with his panoramic view of human evolution. He drew close evolutionary parallels of genome and language—parallels that did not necessarily intersect.

The problem with adaptation in Darwinism lies in the circularity of the concept of fitness. Cavalli-Sforza had a clear view of fitness as the rate of reproduction: the genome that reproduces itself faster is more fit. This approach, being essentially Darwinian,

breaks the vicious circle by offering a quantitative measure of fitness regardless of the material nature of meta-life and identifies fitness with nothing but the observable speed. It is accepted in ALife.

The entire treatment of life as competition of replicating sequences for a limited resource, it must be noted, comes from Manfred Eigen, a Nobel Prize recipient for chemistry (1967). His meta-chemical ideas were originally expressed in Eigen (1971-1978) and later in Eigen and Schuster (1979). Some elements of Eigen's theory, in the form of population dynamics, can be also found in Komarova and Nowak (2003). Eigen used a linguistic example for illustration (Eigen, 1977). This is how the initial sentence evolved after a number of reproductive cycles in a life-like model:

```

1      TAKE ADVANTAGE OF MISTAKE
5      TAKF !DVALTAGE OF MISTAKE
10     TALF ADVALTACE OF MISTAKI
70     TAKEB ?VALTAGI LV MIST!KE

```

The main thesis of kinetics is neither chemical nor physical. It is based on common sense: the more molecules are present in the unit of volume, the higher the probability of their collision, which increases the probability of the successful collisions that lead to transformation. The limited resource in chemistry is strictly material: the fastest reaction pulls the rug under the feet of competing reactions by consuming their starting material, common for all, so that the slower reactions are increasingly suppressed with time.

Eigen's works started the entire area of Artificial Life. They are too technical to be explored here, but a whole host of beautiful and general ideas on evolution, fitness, language, and music, against a rich cultural and philosophical backdrop, can be found in his popular book with Ruthild Winkler, originally published in 1965 (Eigen and Winkler, 1993) well before his detailed works on molecular evolution. It contains a chapter on molecules and language.

I cannot resist the temptation of quoting Eigen on Chomsky: "...we could say that Chomsky's linguistics applies to language in the same way that thermodynamics does to

the weather,” which is hardly a compliment from a natural scientist. For the context, the reader should look for the page 269 of Eigen (1993). In the same book one can also find a discussion of the frequency analysis of intervals in musical compositions very similar to Greenberg’s analysis of Arabic roots. Of course, more modern sources can be found.

The forms of meta-life, other than biochemical life, are language, culture, customs, society, technology, science, art, even some games, and the list is open-ended. All of them originated and have been evolving on the platform of biological life, under which we find nothing but chemical reactions. The term Artificial Life, which originally echoed Artificial Intelligence, can be used instead of meta-life in both meanings: as human simulation of life and as forms of meta-life created by human reason and hands, whether intentionally or as the game of chance and necessity. In the context of Darwinism, the non-biotic life was characterized by Dawkins (1989) as life of **memes**, the cultural and mental counterparts of genes. Note, however, that it was Zipf who first used the expression “genes of thought.”

If we accept the kinetic concept of evolution, then the significance of the main linguistic idea of Zipf (1949, 1965) becomes obvious. The patterns of live speech are selected along the criterion of least effort, comprising the shortest length, fastest utterance, and its fastest subsequent understanding.

To complement the ancient Chinese tale, here is a modern example. The Russian post-Communist revolution brought the abbreviation **MREO UGIBDD GUV**, which itself is so long that it asks for another abbreviation, probably, **MUG**. It means:

The local office of the inter-regional office of technical inspection of transport of the department of state safety inspection of road traffic of the top directorate of internal affairs.

This *Tikki Tikki Tembo* of a kind corresponds to the American **auto registry**.

11. ZIPFING THE CHIMERA

In order to describe a source, we have to flatten, turn into a string, and squeeze its configuration through the bottleneck of speech. This may require breaking some bonds and forming some new ones, which is exactly what chemistry is about. Speech generation, from the point of view of a chemist, is a “chemilingustical” reaction. As any natural process in a non-equilibrium system, it requires **free energy**, which is physical energy in the form convertible into work. It is supplied to humans with food. Naturally, if language helps to get more food, it will survive in a population. There is nothing in thermodynamics, however, that predicts the origin of language. Not intending to engage further in a discussion of this large and difficult topic (see Pinker, 2003), I mention it just to point to a large area of the big picture: the adaptive aspect of language. The very fact that language is an adaptation in no way predicts its structural properties. In a sense, everything that exists in living systems is adaptation.

Figure 11.1 depicts the essence of the process of linearization of a non-linear configuration. The initial state is what is called **image** in PT. It is the configuration of the source processed by organs of perception—another vast topic of cognitive sciences.

The configuration space is the first of the *regular structures* that we are building. The next consists of *images*, a concept that formalizes the idea of observables. In other words, a configuration is a mathematical abstraction which typically cannot be observed directly, but the image can (Grenander, 1996, p. 91).

Unlike thoughts, images in individual minds can be compared and shared by comparing and sharing their verbal descriptions, drawing pictures, imitating, pointing, etc. Two people almost always agree whether the animal in sight is an elephant or a mouse.

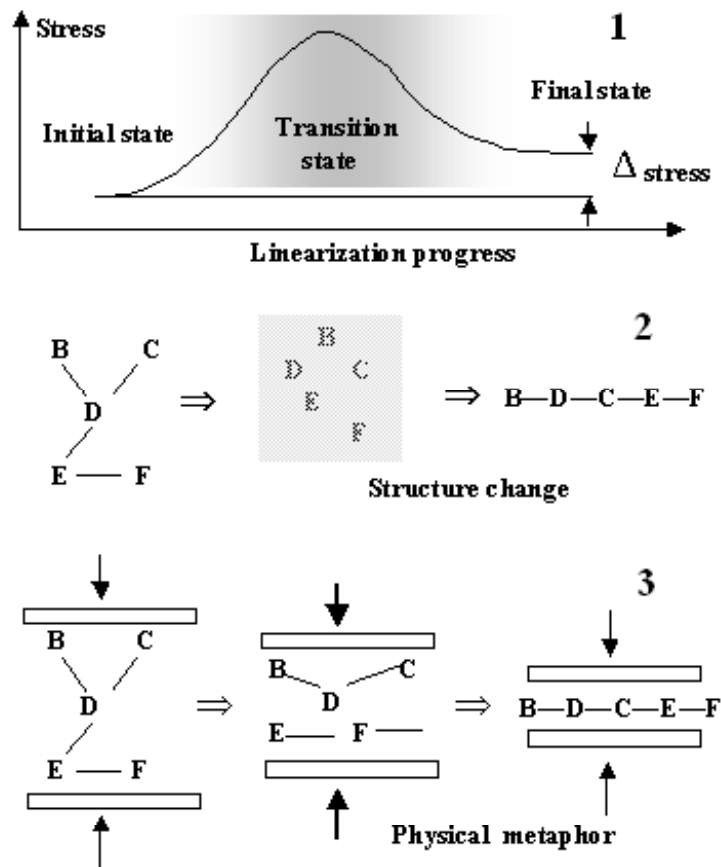


Figure 11.1 Linearization of the source into the output string

A lot of legitimate questions of epistemological character could be asked here: what is the relation between the source and its image? How can we know anything about the source if we have only its images in the brain? Do we really have an image of somebody's image, etc. I will not respond to any of them because, as a chemist with an upbringing of an experimentalist, I have to abide by two principles: to draw the distinction between observable and hypothetical and imaginary objects and the distinction between an established consensus and arguable approaches. This does not mean that I consider philosophy worthless, just the opposite. I believe it is still not only waiting to be

called science but also longing for it. I can only hint that the relation between the “*an sich*” (Kant) configuration and its image in PT may point toward a promising direction of investigation because both are represented in the same mathematical language.

In Figure 11.1 linearization is shown in three aspects:

1. Transition over the stress barrier from the initial to the final state;
2. The structure of the initial and final states with fuzzy intermediate state;
3. A physical metaphor of the process as a mechanical squashing.

In this way the unyielding porcupine of the source is pushed feet first through the apparatus of speech. I like to call this process **zipfing** to emphasize that it must be done with the **least effort** in order to compete with other modes of sound or sign communication. The least effort is required at all stages: to understand the image of the source, to break it up into singlets, doublets, and larger fragments and to align the fragments for the output. Note, that these stages form a cycle because the next stage will be again the understanding by a listener—the situation explored by Simon Kirby, James Hurford and others, see Kirby and Christiansen (2003). This brings us back to the ideas of Manfred Eigen about hypercycle and right into the identification of language as a form of life.

The residual stress (Δ_{stress}) is the measure of the irregularity of the output as compared with the source.

NOTE. A nit-picking chemist, as well as linguist, may inquire about the material balance of generators in linearization. How can we form two doublets with the same generator if there is only one generator of each kind? Here is a hint: there is a population of generators in the mind, similar to a population of molecules in a volume of liquid, but it is a population in time, not in space. For example, stuck in traffic, we repeatedly return to the idea of being late to a meeting, although any idea exists in a single copy. The time population of this idea is much larger under the circumstances than the idea of the world energy crisis.

Figure 11.2 further illustrates the idea of chemilinguistry. In **A**, the resulting triplets have the same degree of stress and are equally probable. The transition state can go either way. In **B**, the resulting **SOV** (Subject-Object-Verb word order) is, arbitrarily, more stressed and less probable than **SVO** because **V→O** in the source changes its

orientation to the irregular $O \rightarrow V$. The least effort condition is partially satisfied if the topology of the source is maximally preserved during linearization. I have to remind that we are dealing here with protolanguage, which has no grammar except the preservation of topology.

In chemistry, the structure that forms behind the lowest transition barrier dominates the final state. This principle, if applied to language, transforms into the following hypothetical definition of grammar in a meta-chemical but by no means metaphorical sense: Grammar is the catalyst of language generation

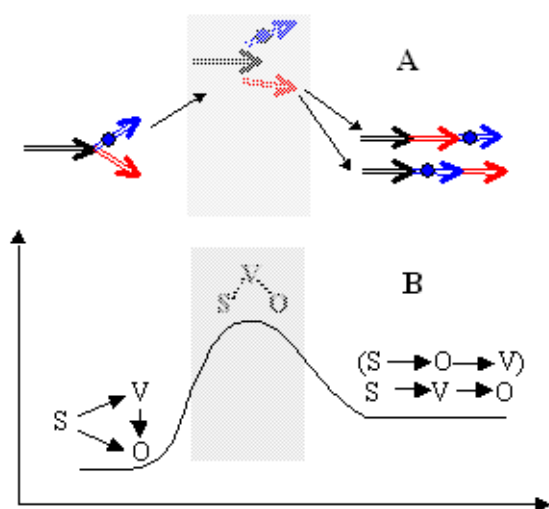


Figure 11.2 Examples of linearization
A: Fork-like source; B: Triangular source

Catalyst in chemistry does exactly this: it decreases the stress (energy) of the transition state. **Grammar** decreases the stress of transition state because of the preservation of linear fragments longer than doublets and because of introducing syntax, i.e., the means of topology preservation other than simple adjacency.

It seems to me that what Noam Chomsky has been searching for is the formula of this catalyst. Of course, this catalyst must be innate and, of course,

it must be part of a larger picture. And of course, we still do not know what it is.

The short run situation, controlled by kinetics, applies only to the spoken language. An assiduous writer who has plenty of time to think and to rewrite the text and is not bothered, unlike Hemingway, by physical ailment, can really put the patience of the reader to a test by exhaustingly long sentences. An elitist writer and elitist reader will find each other like a sadist and a masochist.

As a self-illustration of the Zipf Principle, having little patience by nature, I prefer the short term **stress** to the somewhat longer but more accurate terms **irregularity**, and

improbability. I could also say **energy**, but stress and energy are opposites in pop psychology.

In order to legitimize the use of chemical analogies beyond the general pattern approach, we have to explain in what exactly way the chemical systems are comparable to the language generation systems. And what is catalysis, anyway?

Procreation, cooperation, competition, and social order need acts of contact and exchange. In the molecular dynamical systems the random events of exchange are collisions of particles. Collision is predominantly a binary event. Molecular system has no memory of its previous state, unless it is alive.

Switchboard systems are an alternative kind of dynamical systems. Modern telecommunication makes a physical contact at home or a marketplace unnecessary. Telephone communication is one example. Mind is another one: it acts as a switchboard system on short segments of time and the neurons do not dash around inside the skull.

Figures 11. 3 and 11.4, saving a lot of words, compare molecular and switchboard systems .

The switchboard (SB) dynamical systems are not the same as the **connectionist systems in** Artificial Intelligence, but I cannot refer to any source other than my own description. As far as connectionism is concerned, this is another contentious area from which I would like to stay away.

The SB system is just a mathematical image of a certain spontaneous activity which can be mapped onto molecular processes, while the connectionist networks are through-flow processing systems, usually, with feedback or under external control. The events in SB systems are momentary connections and disconnections between elements of the set of sites presented as small circles on a larger one. The physical and biochemical mechanism of the switching is irrelevant. The contacts involve a certain medium which can enhance the connection or hinder it, as well as remember it for some time. The fading memory of previous connections is represented by dotted lines. There are ephemeral connections, as well as long-lasting ones. The “movement” in the switchboard is spontaneous and has the properties of ordered chaos. This is completely opposite to any computer, even the one simulating ordered chaos.

With all the differences, both molecular and SB systems are, to some extent, conservative. While the isolated molecular system maintains its energy, the SB system requires external **free energy** (i.e., energy in the form capable of introducing order, unlike the chaotic heat) to make and unmake connections. It is thermodynamically open, but the constraints on the supply of energy limit the activity in the same way as temperature limits the average number of collisions in molecular systems. The SB system is thermodynamically similar to life because it stays far from equilibrium until the supply of energy lasts.

I am not aware of anybody working with a computer on a limited energy supply in such a manner that the computer itself is tweaking its software to do maximum computations per unit of energy. Such a computer would be a true model of the mind, but I believe that it could be created only within a population of similar computers exchanging segments of software and capable of errors. The open source software in the community of programmers is close to this form of evolution.

I am sadly aware of a large and menacing boulder of software capable of unpredictable errors but protected by monopoly from selective pressure: I am using it for typing this paper.

Figure 11.3 needs little explanation. The molecular system is a series of collisions and the SB system is a series of connections fading with time. The dramatic difference is that the first one is completely chaotic while the other one is a **dissipative system**. The significance of this fact is enormous, but this is not a good opportunity to expand on it. Instead, the reader should turn to the numerous works, many of them popular, of Ilya Prigogine, for example, Prigogine and Stengers (1984). For a linguist interested in a larger picture, this area, however difficult, could be stimulating. It could suggest, for example, some against-the-tide research aiming at the connection, denied by many, between material culture and the character of a particular grammar. The production of free energy in the form of food is a necessary condition for an evolution of a complex living system. Some languages may be better than others for this purpose and they can themselves evolve faster.

The six images of Figure 11.4 illustrate the concept of catalysis. I will speak about it mostly metaphorically, but excellent popular sites can be found on the Web. First three images portray the molecular systems where particles are chaotically moving. The

catalyst limits the freedom of movement of colliding particles by forming fleeting bonds with them. It works as a biased switchboard operator who tends to connect his friends at the expense of all the others. When the catalyst is immobilized, for example, on a solid surface, the chemists speak about heterogenous catalysis.

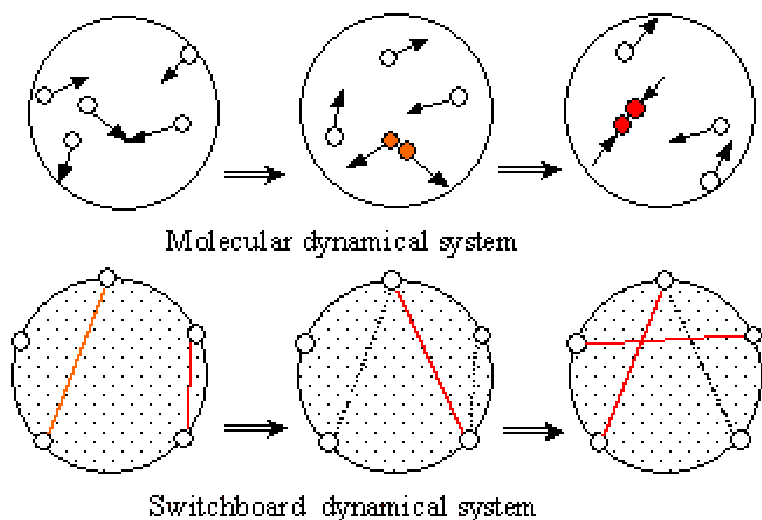


Figure 11.3 Molecular and switchboard systems

In images 5 to 6 the space is topological but non-Euclidean (the latter is also topological). There is no movement in this space and all generators are immobilized. It is the configuration space of PT.

When a connection associates with a **new** generator (here comes **novelty**), it can symbolically represent the connection in any further configuration with its participation. Conversely, the symbol evokes its original meaning (image 5). In the case of learning (image 6), the frequent connection becomes permanent.

Figure 11.5 illustrates the template catalysis, which is employed by life for most important and intimate biological functions. This catalyst is a very large molecule, comparable with text, and it is active only at a small and moving area, as with reading a text. Moreover, as any text, it is capable to copy itself, which is what life means from the point of view of chemistry.

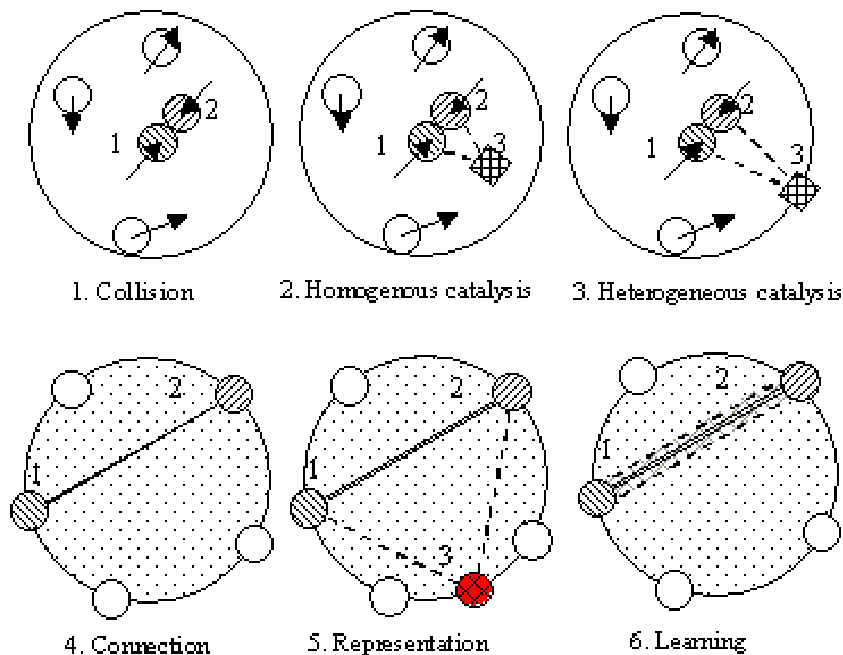


Figure 11.4 Catalysis and learning

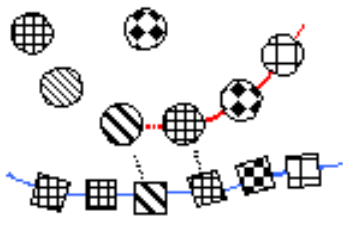


Figure 11.5. Template catalysis

The concept of **transition state**, which I touch upon only superficially in Chapter 9 and here, but more in depth in Appendix 3, is still little known outside chemistry and politics. It has been spreading recently as a new domain of complexity. Transition state begins to look like a paradigm of a universal importance of the same magnitude as thermodynamics and basic laws of nature. It may be underlying a lot of various phenomena, from geological activity such as earthquakes and volcano eruptions to “punctuated equilibrium” in biological evolution to the flight of albatross. It may turn enlightening in the study of evolution of language and society.

The concept of punctuated equilibrium (Eldredge and Gould, 1972, Eldrege, 1985), sharply debated in biology, found a more hospitable soil in sociology, for example, in theory of organizations. The reason for that seems to be rather trivial: social institutions, unlike biological evolution, are directly observable. What follows from the observations in history and sociology—and even from individual human experience—is

the alternation of long (most probable) periods of stability and even stagnation with the turbulent (less probable) periods of intense transition from one stable state to another. In mathematics this pattern is known as Lévy process or Lévy flight.

On a smaller scale, a similar pattern can be seen in the behavior of birds and animals, such as albatross (Viswanathan, *et al* , 2002) and jackal. The imitation of a typical pattern is shown in Figure 11.6.

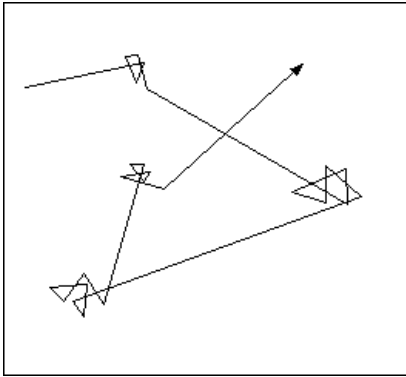


Figure 11.6. The 2D pattern of Lévy flight

The already mentioned work of Ashby (1960, 1964) on modeling homeostasis with a set of interconnected electric devices adds another certificate of generality to the concept of transition state. In his experiments, Ashby used a system of interconnected mechanic units exchanging electric input and output signals with each other. The units could be in one of a series of states each. The system could ultimately find its state of equilibrium. When disturbed by the experimenter,

the system began a frantic and apparently chaotic search for a new state of equilibrium. Having found one, it could stay in it until the next perturbation. Ashby characterized this property of the system as homeostasis. He considered it the basic property of natural and artificial dynamic information systems. This alone was not new. The novelty was in the observation of the excited, unstable, and short-living transition state in a system of a switchboard type. The units, sitting on a bench, exchanged not by collisions but by information. Moreover, it was a dissipative system.

There is a wonderful discussion of punctuated equilibrium and related topics in Lightfoot (1999), who, by the way, mentions both Darwin and Marx as the founders of general evolutionary theory. It is hard to dispute this juxtaposition: in fact, Marx complements Darwin by his concept of history punctuated and driven by revolutions, but he borrowed the idea from Hegel. Anyway, both Darwin and Marx have no peace in their graves.

What is the truth? The truth is a consensus. This is why there is no eternal truth.

More about transition states in society and mind, see Tarnopolsky (2003).

12. A CHEMIST AND A CHIMP SPEAK NEAN

Nean is a sequence of single words and, mostly, word pairs that represent the bond couples in the source by word adjacency. The relative significance of generators in the source (i.e., topicalization, also called focusing) is expressed in Nean by their frequency (this is very PT). An utterance in “English Nean” would look like this:

Ug Og Ug meat

Nean is, actually, a pure grammar and it can be applied to any lexicon, assuming that the words are just labels for generators. We can speak, write, and sign in Nean using words of any language, as well as arbitrary symbols, as long as we have a source and do not fret over the philosophical relation between the “real thing” and its symbol.

I see protolanguage itself as a transition state toward a grammaticalized spoken language. On an evolutionary timeline, Nean sits in the very beginning of the transition to language. Right before the stage of developed language, Nean may take a somewhat more sophisticated form of the “haploid Nean” (see Chapter 7).

Beginning to speak, the children recapitulate the stages of Nean by moving from single words to doublets, triplets, and multiplets.

The subsequent development of grammar is beyond the scope of this paper. Plenty of good ideas can be found in Language Evolution (2003) and large literature, to

which a chemist can hardly add anything. The chimeric approach, however, may illuminate the problem from a particular angle. Thus, we can hypothesize, within the grammaticalization theory, that the inflections develop from words (see a short perspicuous overview by Hurford, 2003), especially those that signify large classes of objects. We can also hypothesize that verb is a later invention (from words like **hand**, **foot**, and **mouth** for verbs **do**, **go**, and **eat**) and this is why the **SOV** word order dominates at earlier stages of language evolution. If we regard the inflected word, like (he) **SPEAK-s**, as a former doublet, later collapsed, the genesis of morphemes with syntactic function becomes a natural continuation of Nean. Uniformitarianism—the idea of deep similarity of all languages—may have a point after all. This is exactly what I mean by saying that all languages perform the same function—linearization of the source configuration—by the same means of preserving binary connections during zipfing (a.k.a., trash-compacting).

My own experience of a translator tells me that it is impossible to render a technical or in any way special text unless the translator has reconstructed a mental image of the source. Moreover, such languages as Legalese and Patentese may require translations from English into English. The situation is more subtle, but basically the same with poetry. Understanding is the ability to convey the source to somebody else. The language cannot be outsourced.

It is sufficient to turn to the reviews by Tomasello (2003), Hurford (2003), and others from the same source to see that my chimeric vision of Nean is by no means revolutionary. There is a lot of hands-on work going on in linguistics that would please a chemist-realist, who would, however, still distrust any computer simulation in which no **thermodynamics** (with an energy-like parameter) and **kinetics** (with a transition state) are involved. What Nean could mean against this positive and energetic background is, paraphrasing Michael Tomasello, an “evolutionary fairy tale with which to **begin**” (instead of “**conclude**,” Tomasello, 2003, p. 108).

In this Chapter, I illustrate the transition from a source to the utterance with examples. If only the meaningful words are left, the **previous sentence** of this paragraph can be in various ways decomposed into doublets, for example:

I illustrate	source utterance
illustrate transition	illustrate example
transition source	Chapter illustrate
transition utterance	(and others)

In a context, the shredded sentence still tells something.

Using haplology, we can obtain some triplets and longer oligomeres:

I illustrate + illustrate transition = I illustrate transition

transition source + transition utterance = transition source utterance

(if there is no doublet utterance source, then transition source
utterance is more probable than transition utterance source).

Chapter illustrate example

etc.; one can play with this linear LEGO.

As it can be seen, the choice between “triangular” structures like transition source utterance or transition utterance source depends on the orientation of the bond between utterance and source. We could see that in a very general form for the basic syntactic formula of word order, Figure 11. 2 (Chapter 11). The linearized configuration will depend on the direction of the **V,O** bond. This is, of course, pure speculation, but it could be up to a linguist to confirm or reject it by observable facts, and, quite possible, such facts are already somewhere in the literature. There could also be a proof that **SVO** corresponds to a better zipfing in a faster moving world with longer utterances. By the way, the growing string length per source applies a harsher selective pressure regardless of the pace of cultural progress.

Figure 12.1 presents further illustrations to the case of linearization of a triplet in the case of the basic word order. The fuzzy non-oriented transition states in the middle column are obtained by breaking a single bond of the source. They lead to the final states in the right column. We can also see how the factor of the relative strength of a bond could work. But what can we say about the invisible transition states, whether in chemistry or in linguistics? Isn't it the same as fighting the Gothic monsters of formal

theory? Well, I can't deny it is, to some extent, but there is an important difference, better seen from the chemical side.

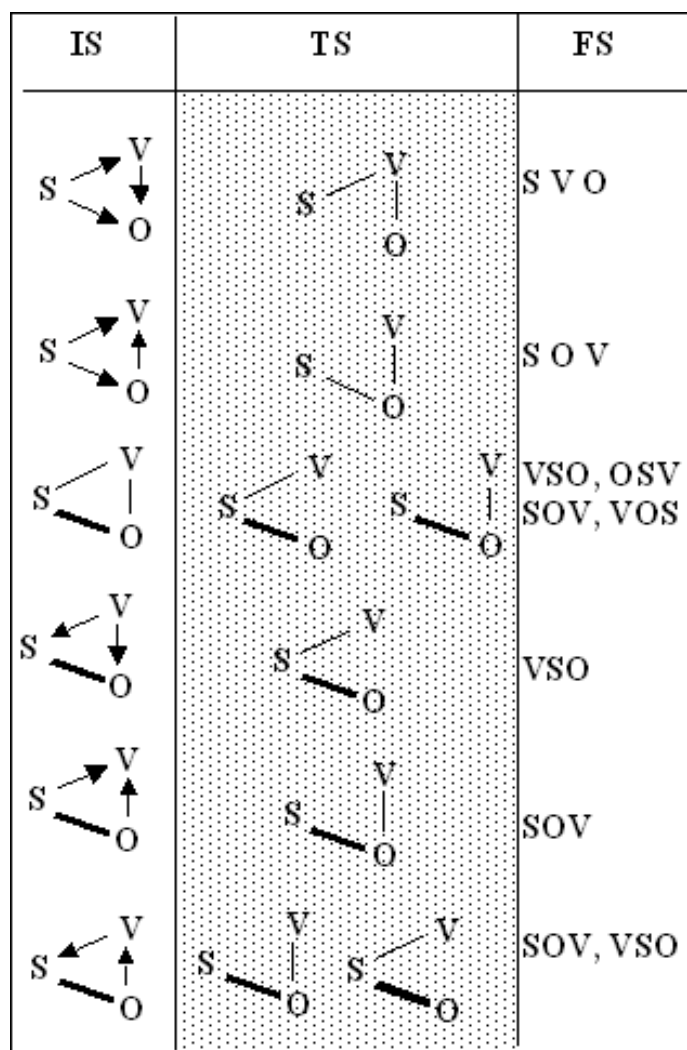


Figure 12.1 Initial (IS), transition (TS), and final (FS) states for S,V,O order. Stronger bonds are marked by thicker lines.

The so-called Hammond postulate in chemistry—one of a few most fundamental ones—illustrates how chemistry handles transition states. George S. Hammond (Hammond, 1955), being perfectly aware that his postulate was unprovable at the time (it could be proved or refuted someday), thus formulated his idea in the language comprehensible by a chemolinguist:

If two states, as for example, a transition state and an unstable intermediate, occur consecutively during a reaction process and have nearly the same energy content, their interconversion will involve only a small reorganization of the molecular structures. (Hammond, 1955).

It means that if two structures along the transition pathway have similar stability, they have similar structures. One of the corollaries is that in the beginning, the transition state is closer to the initial and in the end to the final state.

What Hammond did was taking the general idea of transition state formulated in terms of energy from physics and adding to it the structural aspect alien to physics. Hammond postulate is so general and so extra-chemical because it is stated in two universal scientific terms that belong to all natural sciences: energy and structure. It is the “lack of energy,” sorry for the pun, that distinguishes all formal linguistic theories.

I have no firm ground under my feet, however, when stepping on a linguist’s turf. It is quite possible that the formal theory is compatible with an adapted Hammond postulate in one form or another.

What Hammond postulate itself lacks, sharing this shortcoming with formal linguistics, is the evolutionary aspect. It is of no importance whatsoever in the chemistry of simple systems, but is crucial in the study of any complex natural system, such as language or biochemistry. All those systems have evolutionary memory. The generalization of the concept of transition state over the evolutionary transformations, which I suggest, would mean at least a temporary completion of the universal theoretical framework for complex systems, provided the non-equilibrium thermodynamics is also included in the picture.

The order in which the generators of the source configuration historically appeared—the heredity and genealogy of the language—is an important part of the explanation of its current state.

And in some cases this new function of the word is the first instance of this function being fulfilled at all, in the language concerned (Hurford, 2003, p. 52).

In other words, the present of the complex system depends on its past. Chemistry is based on the opposite principle: the properties of a molecule do not depend in any way on its origin.

To be more exact, the distant future of the complex system depends on its close past.

To complement the above quotation from George Hammond, here is a quotation from Nim Chimpsky, an educated chimp:

Give orange me give eat orange me eat orange give me eat orange give me you.

(Terrace, 1970, p.210)

This is a perfect Nean.

Still, I will have the last word, quoting myself, see page 29:

$\text{C}-\text{H}_1$, H_1-C , $\text{C}-\text{H}_2$, $\text{C}=\text{O}$, H_1-C , $\text{O}=\text{C}$, $\text{C}-\text{H}_1$, $\text{C}=\text{O}$!!!

Hey, my Nean is as good as Nim's.

13. SCENES FROM THE CAVE LIFE TOLD IN NEAN

Hurford (2003, p. 53) notes that the study of grammaticalization requires going backwards from the modern to the earlier and simpler stages of language. Thinking backwards from the products of a transformation to its initial state plays an important role in the daily work of the chemist. For example, thinking about the best way to synthesize a naturally occurring drug, an industrial chemist develops a converging tree of routes leading to the goal. Another chemist may imagine a different tree of pathways leading to the natural synthesis of the drug in the plant. As the next step, both have to select a few most probable transformation chains, which is done using different selective criteria. The industrial chemist uses the overall cost as the criterion, trying to involve a minimum of intermediaries and byproducts, while the biochemist looks for particular intermediaries and byproducts. Let us take note of both completely compatible investigative approaches. In criminal investigation, the first is echoed by *cui bono*, looking for the one who profits most from the crime, while the second corresponds to collecting material evidence.

Figure 13.1 shows three kinds of problems arising in chemical research that are common for all studies of structural transformations, including human history and politics. Another general question can be added to them: what else could happen?

It is impossible to reconstruct the origin of language in the absence of any however fragmentary data, i.e., intermediaries and byproducts, in the chemical parlance.

What may be possible is to understand the principles that guide the evolution and find or reinterpret some evidence available at its later stages.

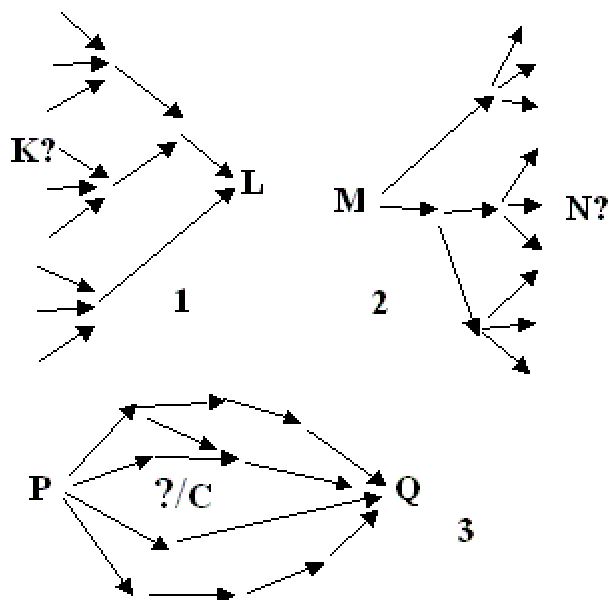


Figure 13.1 Three kinds of chemical investigation:

1. Can L come form K? 2. Will M generate N?

3. Which pathway from P to Q is optimal regarding condition C?

In this Chapter, I would like to recapitulate some ideas and expand on the chimeric principles of historical investigation of protolanguage, without claiming any positive results, but using positive examples.

Since we are interested in the development of language from protolanguage, let us, as it is appropriate for a chemist, go back from the following **full-language** expression:

In the cave Ug grimly gives a bone to Og.

The source of the expression is an image of a situation in the (non-Platonian) cave. The complete situation, which may not be seen in all detail by each witness, can be more complex, regarding the background, participants, objects, time, weather, motives,

physical health, social tensions, etc., and a history, in which the current source is just a limited projection (image) of the most recent episode.

Our strategy is to **hypothetically** reconstruct the way from the source toward its transformation into the linear expression, using our knowledge of the caves, inanimate objects, animals, humans, and their interaction. We assume that the laws of nature were the same in the ancient cave as they are today.

We can attempt the reconstruction by comparing various sources that can lead to the same expression. We can do that only by using the same language for both source and expression, which is the language of PT: our objects are configurations with a connector graph and numerical properties of the generators and bond couples. These properties are similar to the numbers in the Greenberg tables, but here we assign them to a large extent arbitrarily and just see what comes out of it. The following play with various sources is similar to chemical experiments in which we change conditions, observe the results, learn something, and design new experiments to learn more.

To portray the source configurations, we will use a large circle with generators positioned on it as small circles, symbolizing the switchboard system. The bonds may have direction and be of negative strength, corresponding to repulsion.

It is necessary to establish some principles of attributing direction to a bond. We can assume that there is a certain order of precedence between generators. For example, both **Ug** and **Og** have, probably, existed for about twenty years, but the **bone** appeared only today. This is why we have **Og** → **bone** orientation. Similarly, the good old **Ug** gives the freshly cleared **bone** only today and not everyday: **Ug** → **give**. By the same logic, we should direct **give** to **Og**: **give** → **Og**. The configuration of **Source 1** is largely arbitrary. Our goal is not the right configuration but to see how the change of the source influences the transition state and the output.

We don't know what is true. Again, the truth is a stable consensus, always temporary. More on this subject, see the famous Kuhn (1962), which is another illustration to the theory of transition state.

I need one more digression. Note, that this approach has to keep in both the source and its representation in the same frame. Therefore, **hypothetically**, knowing something about the evolution of the source, for which we may have some hard archeological data, we may draw conclusions about the language change. This is not a popular point of view, but Newmayer (2003, p. 73) tends to go against the (political correctness) tide and there is not a single principle of nature to support the tide.

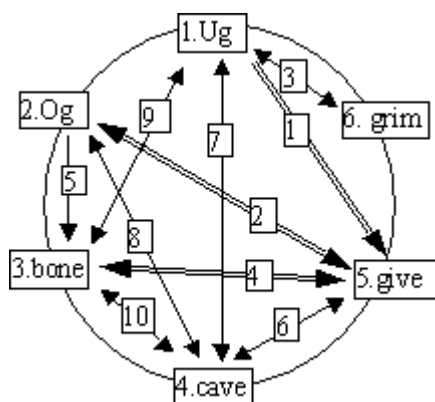
Thus, it seems probable that the English language experienced one of the most dramatic changes because of the active, turbulent, and charged with energy social evolution, plus the ethnic mixing of England during its early history. The cultural factors (education, press) later stabilized the evolution.

The long and well documented history of Sumerian language is a great source of evolutionary facts (for a quick look, see Halloran, WWW), although not about the spoken form. Lightfoot (1999) assembled and analyzed rich and intriguing material on language change in his both detailed and “high-ground” book and placed it on a large picture with history as natural process in its center. I believe that the research in the co-evolution of economy, social order, culture, and language may bring some positive results. Language, like tea in England, beer in USA, vodka in Russia, and maté in South America are means of social bonding.

Bottéro (1992), in his breathtaking book, gives a remarkable opportunity to peek into the mechanics of the ancient mind through the tablets with interpretations of dreams. We see how words become the source of thoughts, reversing the usual order.

Let us start with the following source:

Source 1



This configuration reflects our belief that it is **Ug** who looks **grim** (bond 3 between generators 1 and 6), **Ug** may or may not **give** and is, therefore, a primary generator regarding **give**, bond 1 directed toward generator 5 and is especially strong, etc. We direct bond 5 toward **bone** and just see what follows. The picture is utterly hypothetical and intentionally complex: everything seems connected to everything.

Of course, it is not: neither **bone** and **grim** nor **Og** and **grim** interact. Unreasonably, however, the bond **Ug – Og** is absent.

The generators of the configuration are labeled by six numbered words in the list:

words = Ug Og bone cave give grim
 1 2 3 4 5 6

The source configuration is coded in the 6 x 6 connectivity matrix, the non-zero elements of which are the bond affinities, taking only two arbitrary values, 1 and 2. Instead of **affinity** I will use a shorter **score**. The bond with score 2 is stronger (more probable) than the bond with score 1 and it is denoted with a double line. The diagonal could, in principle, reflect the weights of the generators. For the sake of experimentation, the scores are assigned to the bonds intuitively and tentatively.

	1	2	3	4	5	6
1	0	0	1	1	2	1
2	0	0	1	1	2	0
3	1	0	0	1	2	0
4	1	1	1	0	1	0
5	0	2	2	1	0	0
6	1	2	0	0	0	0

For practical reasons, we will code the same information in the form of sparse matrix **S**, which lists not the generators but the non-zero bonds.

S =

1	1	5	2	1
2	2	5	2	2
3	1	6	1	2
4	3	5	2	2
5	2	3	1	1
6	4	5	1	2

7	1	4	1	2
8	2	4	1	2
9	1	3	1	2
10	3	4	1	2

Columns: 1 2 3 4 5

In rectangular matrix **S**, the first column is the bond number, next two columns are a pair of connected generators, column 4 contains the score of the bond and the last column indicates whether the bond is directed (1) or not (2) from the first to the second generator in the row.

The linearization is performed by a simple MATLAB program called, as the language, **nean** (Appendix 4), which can be easily modified and improved by anybody more experienced in programming than myself. It is probably easier to create it from scratch.

The input data are matrix **S**, array **words**, integer **NN** and real number **score**.

Example: The input of **words** and **S** for **Source 1** is:

```
words= ['Ug ' ; 'Og ' ; 'bone ' ; 'cave ' ; 'give ' ; 'grim '];
```

```
S =[1 1 5 2 1; 2 2 5 2 2; 3 1 6 1 2; 4 3 5 2 2; 5 2 3 1 1; 6 4 5 1 2; 7 1 4 1 2; 8 2 4 1 2; 9 1 3 1 2; 10 3 4 1 2];
```

The program does the following:

1. Using the function of **random permutation**, it generates a random linear sequence of generators in **words**;

Example: Ug bone cave give grim Og

2. checks each pair of neighbors against the matrix **S** of the source configuration.

Example: Yes, Ug is coupled with bone, ...No, Og is not coupled with grim.

3. calculates the sum of all adjacent generator pairs that are connected in **S** and adds it to the overall **score** of the sequence;

4. repeats steps 1 to 3 **NN** times and compounds a list of all different permutations in **words** with the same total **score**.

It is not absolutely necessary, but Nean needs the number of cycles **NN** large enough to guarantee that all possible permutations are checked against the total **score** criterion for all selected sequences. Translating into Chemicalese, the number of molecular collisions should be large enough.

Important! The goal of the program is to simulate a completely random process, similar to molecular collisions. It does not code any intellectual activity and contains no algorithm other than calculating (not simulating!) the total score and counting identical strings. Its algorithmic part relates only to packaging the data, not generating them, because no algorithm exists for a random sequence. Computer can only imitate random (actually, pseudo-random) numbers. **The universal grammar for Nean cannot be learned: there is nothing to learn. Chaos is inherent in any large natural system such as the mind.** What cannot be learned has no source and is **new** and autopoietic, i.e., self-emergent. The **learnable grammar** starts with the haploid Nean.

Here is a typical output of program nean:

Og give bone cave Ug grim
bone give Og cave Ug grim
cave Og give bone Ug grim
grim Ug bone give Og cave
grim Ug cave Og give bone

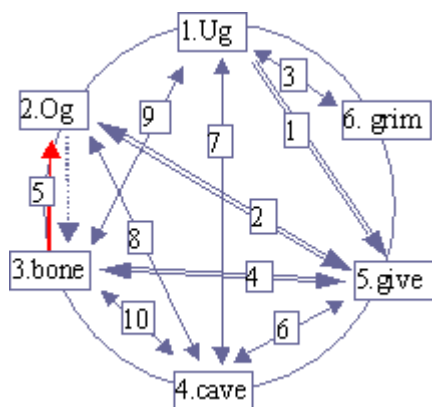
grim Ug cave bone give Og
grim Ug give Og **bone cave**
grim Ug give **Og cave bone**
grim Ug give bone cave Og

number of cycles NN=5000, run time: t=0 min,
score = 7, score matches 60, number of strings 9

There are no sequences with the score over 7. The lower score input leads to a larger number of sequences. The total number of permutations is $6!=720$.

Conclusion (not surprisingly): A complex and confusing source leads to a highly degenerated and confusing output.

Source 2.



The only change in **Source 2** is the reversal of bond 5: **bone** → **Og** instead of **Og** → **bone**. We can regard it a mutation in **S**:

S = [1 1 5 2 1; 2 2 5 2 2; 3 1 6 1 2; 4 3 5 2 2; 5 **3 2** 1 1; 6 4 5 1 2; 7 1 4 1 2; 8 2 4 1 2; 9 1 3 1 2; 10 3 4 1 2];

Og give bone cave Ug grim
 bone give Og cave Ug grim
 cave Og give bone Ug grim
 grim Ug bone give Og cave
 grim Ug cave Og give bone

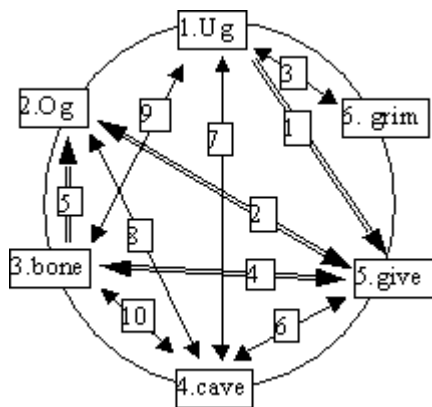
grim Ug cave bone give Og
 grim Ug give Og **cave bone**
 grim Ug give **bone Og cave**
 grim Ug give bone cave Og

number of cycles: NN = 5000, run time: t=0.13723 min,
 score= 7, score matches 47, number of different strings 9

The change, as compared with **Source 1**, is emphasized in bold print.

The ambiguity, therefore, remains. Nevertheless, we notice that six out of nine sequences for both sources start with **grim Ug**, so that the initial position of the subject has a better chance to be generated at random.

Source 3



Intuitively we can guess that the ambiguity can be resolved by:

1. Introducing **take** or Passive, which can be done only through grammar or lexicon.

2. Strengthening $S \rightarrow V$ or $S \rightarrow O$ bond

We increase the strength of bond 5:

$S = [1\ 1\ 5\ 2\ 1; 2\ 2\ 5\ 2\ 2; 3\ 1\ 6\ 1\ 2; 4\ 3\ 5\ 2\ 2; 5\ 3\ 2\ 1; 6\ 4\ 5\ 1\ 2; 7\ 1\ 4\ 1\ 2; 8\ 2\ 4\ 1\ 2; 9\ 1\ 3\ 1\ 2; 10\ 3\ 4\ 1\ 2];$

The effect is striking: a single sequence at score 8.

grim Ug give bone Og cave

number of cycles: NN = 5000, run time: t=0.16667 min,

score= 8, score matches 4, number of different strings 1

For comparison, at score=7 we have a terrible degeneration:

Ug give bone Og cave grim
Og give bone cave Ug grim
 bone Og give cave Ug grim
 bone give Og cave Ug grim
 cave Ug give bone Og grim
 cave Og give bone Ug grim
 cave grim Ug give bone Og
 give bone Og cave Ug grim
 grim Ug bone Og give cave

grim Ug bone give Og cave
 grim Ug cave Og give bone
 grim Ug cave bone Og give
 grim Ug cave bone give Og
 grim Ug cave give bone Og
 grim Ug give Og cave bone
 grim Ug give bone cave Og
 grim Ug give cave bone Og
 grim cave Ug give bone Og

number of cycles: NN = 5000, run time: t=0.169 min,

score = 7, score matches 129, number of different strings 18

The resolution of ambiguity may come from a simplification of the source: only a few bonds decisively contribute to the score. Or: Don't look around, focus!

As we could expect, the complexity of language comes from the original simplicity of protolanguage. With only a few words in the source, it becomes possible to express some of source configurations in an ordered-chaos way in spite of the completely random generation.

Source 4

Moving backwards from complexity to simplicity, we leave only the strongest bonds of **Source 3** in

Source 4:

S = [1 1 4 1 1; 2 2 4 1 2; 3 4 3 1 2; 4 3 2 1 1];

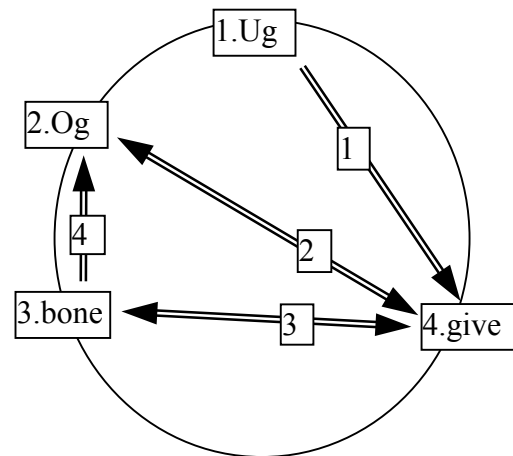
words= ['Ug '; 'Og '; 'bone '; 'give '];

The output is singular at a very low score:

Ug give bone Og

number of cycles: NN = 1000, run time: t=0.0072833 min,

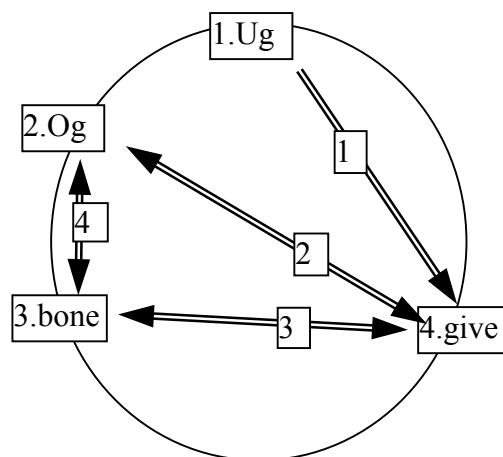
score = 3, score matches 40, number of different strings 1



Source 5

Unless we know it for sure, there could be an inherent ambiguity about G2 and G3: first was Og, then bone or first was bone, then Og?

Lets us make Bond 4 bi-directional:



Ug Og give bone
 Ug bone Og give
 Ug bone give Og
 Ug give Og bone
 Og Ug give bone
 Og give bone Ug

bone Ug give Og
 bone Og Ug give
 bone Og give Ug
 bone give Og Ug
 give bone Og Ug

number of cycles: NN = 5000, run time: t=0.04635 min,

score = 2, score matches 2326, number of different strings 11

As result a whole array of word orders arises. The asterisk stands for indirect object Og.

SVO

Ug * give bone
 * Ug give bone
 Ug give * bone

SOV

Ug bone * give
 Ug bone give *

OSV

bone Ug give *
 bone * Ug give

VOS

* give bone Ug
 give bone * Ug

OVS

bone * give Ug
 bone give * Ug

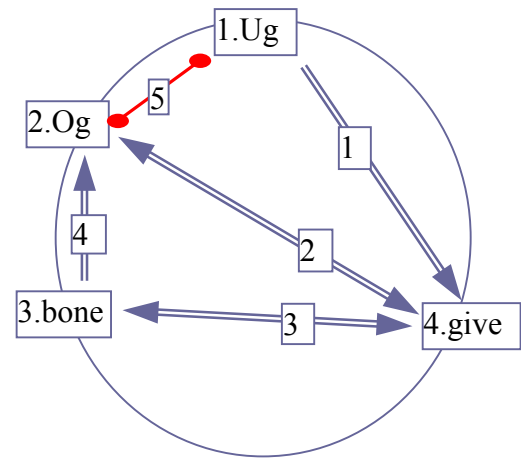
Source 6

Let us introduce antagonism Ug—Og by assigning a negative value to bond 5.

$S = [1\ 1\ 4\ 1\ 1; 2\ 2\ 4\ 1\ 2; 3\ 4\ 3\ 1\ 2; 4\ 3\ 2\ 1\ 1; \mathbf{5\ 2\ 1\ -1\ 2}]$;

words= ['Ug '; 'Og '; 'bone '; 'give '];

At score =3:



Ug give bone Og

number of cycles: NN = 5000, run time: t=0.054 min,
score = 3, score matches 237, number of different strings 1

At score =2:

Ug bone Og give
Ug bone give Og
Ug give Og bone

Og give bone Ug
bone Ug give Og
bone Og give Ug

number of cycles: NN = 5000, run time: t=0.056 min,
score = 2, score matches 1259, number of different strings 6

Now let us increase the antagonism:

$S = [1\ 1\ 4\ 1\ 1; 2\ 2\ 4\ 1\ 2; 3\ 4\ 3\ 1\ 2; 4\ 3\ 2\ 1\ 1; \mathbf{5\ 2\ 1\ -2\ 2}]$;

Ug bone Og give
Ug bone give Og
Ug give Og bone

Og give bone Ug
bone Ug give Og
bone Og give Ug

number of cycles: NN = 5000, run time: t=0.044 min,
score = 2, score matches 1277, number of different strings 6

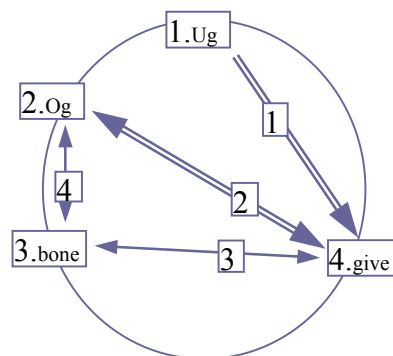
Next, we make GIVE predominantly a function of two variables:

$S = [1 \ 1 \ 4 \ 1 \ 1; 2 \ 2 \ 4 \ 1 \ 2; 3 \ 4 \ 3 \ 0.5 \ 2; 4 \ 3 \ 2 \ 0.5 \ 2];$

At score = 2.5:

Ug give Og bone

number of cycles: NN = 5000, run time: t=0.045 min,
score = 2.5, score matches 217, number of different strings 1



At score = 2:

Ug give bone Og
bone Ug give Og

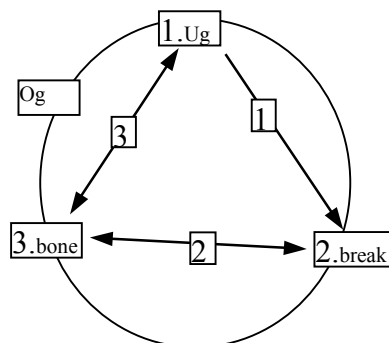
number of cycles: NN = 5000, run time: t=0.045 min,
score = 2, score matches 397, number of different strings 2

Source 7

Basic word order.

words= [' Ug '; 'break '; 'bone '];
 $S = [1 \ 1 \ 2 \ 1 \ 1; 2 \ 2 \ 3 \ 1 \ 2; 3 \ 3 \ 1 \ 1 \ 2];$

Ug break bone
Ug bone break
break bone Ug
bone Ug break



number of cycles: NN = 5000, run time: t=0.027 min,
score = 2, score matches 3309, number of different strings 4

COMMENT: the information about **S** and **O** is preserved. The relationship between **Ug** and **bone** is unclear. What bone?

Next we differentiate bond strength:

bond 1, score 2; bond 2, score 1.5; bond 3, score 1 .

```
words= [' Ug  '; 'break '; 'bone '];
S  =[1 1 2 2 1; 2 2 3 1.5 2; 3 3 1 1 2];
```

At score = 2.5:

```
Ug  bone break
break bone  Ug
```

number of cycles: NN = 5000, run time: t=0.025 min,
score = 2.5, score matches 1664, number of different strings 2

At score = 3:

```
bone  Ug  break
```

number of cycles: NN = 5000, run time: t=0.024 min,
score = 3, score matches 880, number of different strings 1

At score =3.5:

```
Ug  break bone  (now we are speaking English!)
```

number of cycles: NN = 5000, run time: t=0.02 min,
score = **3.5**, score matches 819, number of different strings 1

Note a high probability of the expression: 819 out of 5000, or 16%

Here is another try at the distribution of bond scores.

```
words= [' Ug  '; 'break '; 'bone '];
S  =[1 1 2 2 1; 2 2 3 1 2; 3 3 1 1.5 2];
```

At score = 2.5:

```
Ug  bone break
break bone  Ug
```

number of cycles: NN = 5000, run time: t=0.026 min,
score = 2.5, score matches 1669, number of different strings 2

At score =3:

```
Ug  break bone
```

number of cycles: NN = 5000, run time: t=0.025 min,
score = 3, score matches 866, number of different strings 1

At score = 3.5:

bone Ug break

number of cycles: NN = 5000, run time: t=0.026 min,
score = 3.5, score matches 831, number of different strings 1

From the point of view of chemilinguistry, the above experiments are meaningless because they have no real linguistic context. My goal was limited to a demonstration of a possible tool, the application of which is up to nobody but a linguist. This chemolinguistic tool could be just a part of a much larger tool kit combining structural, thermodynamic, kinetic, and evolutionary approaches, and, most importantly, the realistic sources.

A pretty close model approximation to language as natural process is the theater stage where the spectators can see the action and the background, hear the actors, and have different opinions about what is going on. To study language as natural process without approximation, we have to let others watch our daily and nightly life.

13. CONCLUDING REMARKS

For conclusions one should go back to Chapter 2, *Preview*. Here I would add a few notes about the relation between chemistry and linguistics.

I strongly doubt—together with many linguists—that we will ever be able to reconstruct the genesis of language as it indeed happened. We will simply have no evidence, unless we find, as Baron Munchausen did (Raspe, WWW, Chapter IV), some frozen sounds of the primeval chat preserved in the permafrost.

What we can do, however, is to see how it could and could not have happened in principle and to check the theory on practical development of vocal communication between humans and computers, as well as between androids and, God forbid to omit, gynoids. What we ultimately need is the study of language as a **natural process** and not just an insightful computer simulation or the intellectual game of “why not” and “what if.” This is where chemistry and linguistics find themselves in the same naturalist society.

As recent American political history shows, we can reach remarkable heights with surprisingly limited language skills. Besides, eloquence does not come from the knowledge of linguistics. A reasonable question from an outsider is: Why do we need linguistics at all?

There is more to language than utility: like air, sea, and mountains, it is a beautiful and delightful medium for humans. It is also the starting point of their mating rituals and the endpoint of the relationships. As observation and study of nature, the study of

language will always kindle the interest of lay people and, probably, even of the future androids and gynoids.

Reading the recent overview of the problem of genesis (Language Evolution, 2003), a natural scientist could feel some professional gratification: linguistics is becoming an exciting **natural science**. Moreover, as one can feel especially from the essay of James R. Hurford (Hurford, 2003), it is part of a much larger paradigm shift or, I would say, transition state, in science as a whole. Regretfully, it is too little known how much chemistry has contributed to the large picture of the world, apart from explaining the most intimate mechanism of life.

There are countless variations in linguistic literature on the theme of Humboldt: “the infinite use of infinite media,” see an intriguing discussion in Studdert-Kennedy and Goldstein (2003). This is where the sister sciences tend to go separate ways. For the chemist, the potential infinity of atomic combinations is of no relevance. There is a strict division into the **existing** and the **hypothetical**, on the one hand, and the **known** and the **new** chemical entities, on the other hand. The latter immediately turn into known as soon as their descriptions are published, but there is a daily deluge of new ones.

In some areas of linguistics, any written or spoken sentence is as good as any other, regardless of whether it was repeatedly used in real life situation or not, unless it is “ungrammatical” from the point of view of a language maven. For the chemist, the existence of a chemical compound must be proved by its synthesis and isolation. Nevertheless, not only can we hear ungrammatical sentences all around us, but our entire civilization is built of the daily tide of right and wrong, heresy and orthodoxy and, as chemistry tells us, life itself developed from errors.

The chemical view of the world is part of the general non-Newtonian, non-Einsteinian, and non-quantum (in spite of the quantum theory being the deep foundation of chemistry) paradigm that began to penetrate, first, sciences and then to knock on the door of humanities after the first works of Ilya Prigogine and the first steps of Artificial Intelligence. I believe that the shift took hold between 1950 and 1980. The term “science of complexity,” as the new area is called (Kauffman, 1993, 1995), is awkward and calls for zipfing, but is precise. A great course of complexity by Parwani (2002) is available

online. I wish we could say *omnistics*. Just a look at the contents will give the reader the true taste of omnistics: it is about everything but the string theory.

As I would define its major attribute, omnistics is the study of objects in non-Euclidean spaces, namely, discrete topological spaces in which life, mind, and society have developed their overwhelming complexity and which we know not so much through instruments and gauges as through words and countable numbers. The geometry of this world is an open and partially renewable set of points with their neighborhoods. An object, including a sequence of words and an intricate idea, is represented by a sparse matrix. Distance in this space is quantifiable not with a tape measure but with integers corresponding to the minimum of elementary changes from one structure to another. The change of an object is a change in the matrix. It is governed either by non-equilibrium thermodynamics or by human intent. The open character of the matrix is incompatible with fundamentals of the “pre-complexity” physics and even most of mathematics, in whose systems nothing **new** can happen, although a new system can always be invented.

I believe that Pattern Theory is a welcoming portal into this entire area, where the chemist feels at home and so could the linguist. The growing vocabulary of the human race, in spite of the constant loss, is the best evidence that novelty exists.

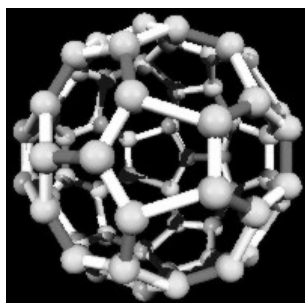
Moreover, I believe that PT opens the door not only into the chemistry of language, but also into the chemistry of thought, i.e., the evasive and murky transition states of the mind. Grenander (2003) offers a look over the threshold of the mind and enthusiasts are welcome.

Language itself is the portal into Everything, where we can find chemistry, a cookbook, and a story about the origin of the portal itself ...if we speak the language of Everything.

15. APPENDIX

15.1 Example of Chemicalese

The structure in Figure 14.1 belongs to C_{60} . The spherical molecule contains only carbon



and belongs to the class of fullerenes, which gave birth to the entire area of nanotechnology. Its root morpheme **fuller** was derived from the name of the famous American architect Richard Buckminster Fuller who designed geodesic domes. The ending **–ene** means the presence of double bonds. The hexagons have the skeleton of benzene.

Figure 15.1 C_{60} , fullerene.

The double bonds are shown dark

The nomenclature name for C_{60} is:

Hentriacontacyclo[29.29.0.0.^{2,14}.⁰^{3,12}.⁰^{4,59}.⁰^{5,10}.⁰^{6,58}.⁰^{7,55}.⁰^{8,53}.⁰^{9,21}.
⁰^{11,20}.⁰^{13,18}.⁰^{15,30}.⁰^{16,28}.⁰^{17,25}.⁰^{19,24}.⁰^{22,52}.⁰^{23,50}.⁰^{26,49}.⁰^{27,47}.
⁰^{29,45}.⁰^{32,44}.⁰^{33,60}.⁰^{34,57}.⁰^{35,43}.⁰^{36,56}.⁰^{37,41}.⁰^{38,54}.⁰^{39,51}.⁰^{40,48}.⁰^{42,46}]hexaconta-
 1,3,5(10),6,8,11,13(18), 14,16,19,21,23,25,27,29(45),30,32(44),33,35(43),
 36,38(54),39(51),40(48),41,46,49,52,55,57,59-triacontaene [14].

Shortcuts are used also in chemical structures, as they were used in all hieroglyphic systems of writing, for example, *n*-Bu stands for $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{—}$ and A stands for adenine in nucleic acids and their fragments.

15.3 The chemical view of the world

The chemical view of the world is very much different from that of a physicist or a computer scientist, but it is only recently that chemistry began to realize its own extra-chemical abilities (Bhushan, 2000). Even before the advent of computers, chemical analogies inspired some landmark works in sociology and social psychology. In computer models of modern economics, an agent looks very much as an upgraded, animated, educated, greedy, and optimistic molecule. What a contrast with chemistry where any molecule dreams only about losing its energy.

Chemists have a simple view of complexity: it is built gradually, step-by-step. A large natural complexity can be built only as result of long evolutionary *history*. The reasons behind this belief are of kinetic nature: a collision of more than two particles is very rare. Nevertheless, complex proteins, as well as minds and societies, manage to assemble. The concepts of chemical mechanism and stepwise concatenation of transformations constitute a historical dimension of chemistry.

Since each elementary transformation is local, the simultaneous occurrence of a significant number of elementary transformations is improbable. In other words, the history of a natural complex system is Poissonian rather than Gaussian. The Gaussian system, synonymous with non-locality, in which any state can, theoretically, follow any other, always comes to an equilibrium while the Poissonian system just drags along from one rare event to another, between which nothing happens, and has no final state.

As far as social evolution is concerned, even wars, which seem to be most common events throughout human history, follow the Poisson distribution (Richardson, 1993), probably, because they are usually initiated by a decision of single person of a limited imagination. From the modern physical point of view, partially influenced by chemistry, all processes in the world are local (Mack, 2001, WWW).

There is a definite appeal in further exploration of the chemical paradigm in the vast area of mind, society, and language. Chemistry possesses the recursivity and generativity that is considered a unique property of human language noted in all general reviews (Calvin, 2000).

It is difficult to categorize chemistry as probabilistic because the large numbers of participating molecules ensure determinism. Yet determinism is absent from the foundation of chemical paradigm. The chemical process, once started either by a chemist or accidentally, runs its course on its own through a series of random events. The chemical system consisting of either large or small number of molecules searches for a new state by random collisions between molecules, “trying on” various combinations and mutual orientations. While classical robots and computers follow a program created by a programmer, the chemical system knows only fast parallel computing based on one operation: drawing a random number. In human reproduction, for example, conception is a reaction between just two molecules and it leads to spectacular results of microcosmic dimension.

Quantitatively, chemistry is mostly focused on time aspects, balance of energy, and irreversibility. At the same time, the meticulous, matter-of-fact representation of chemical events as a sequence of elementary acts, with the behavior of an individual molecule in the focus of attention, brings chemistry on the common descriptive grounds with humanities, especially, history, sociology, and even biography. In his *Selective Affinities*, Goethe (1988) was, apparently, the first to bring chemical symbolism into the chemistry of human relations.

The seemingly shapeless and amorphous appearance of chemistry, which often disheartens non-chemists, may obstruct the view of the mental workshop of a chemist who uses very sharp logical and measuring instruments and exercises a complete freedom of imagination in dealing with immense and incompressible complexity, as well as the experimental rigor, to rein it in. What streamlines the chemical thinking can be formulated as: everything is possible, but most of the possible is improbable and what is probable is local.

Chemistry shares the principles of atomism, composition, and metrics with Pattern Theory. Chemical systems can be regarded as systems of symbolic dynamics where atomic symbols combine and recombine. Therefore, we can hope to design open, evolving, and autopoietic (self-originated) symbolic systems within the framework of PT serving as a kind of meta-chemistry. In order to do that, we must preserve a certain

degree of chemical realism in the symbolic dynamics. In addition, the transition from one state to another must include a random component.

Next I am going to present in a very simplified and vulgarized form some basic ideas of theoretical organic chemistry.

Figure 13.1 consists of three rows (A, B, C) and three columns (I, II,III). The upper row of the Figure 13.1 (A) shows a typical example of a reaction mechanism taken from a chemical textbook and known as SN2, which means Substitution Nucleophilic Bimolecular.

A linguist is as little expected to be familiar with chemical theory as a chemist with transformational grammar. Nevertheless, some general properties of **A** can be seen on the surface.

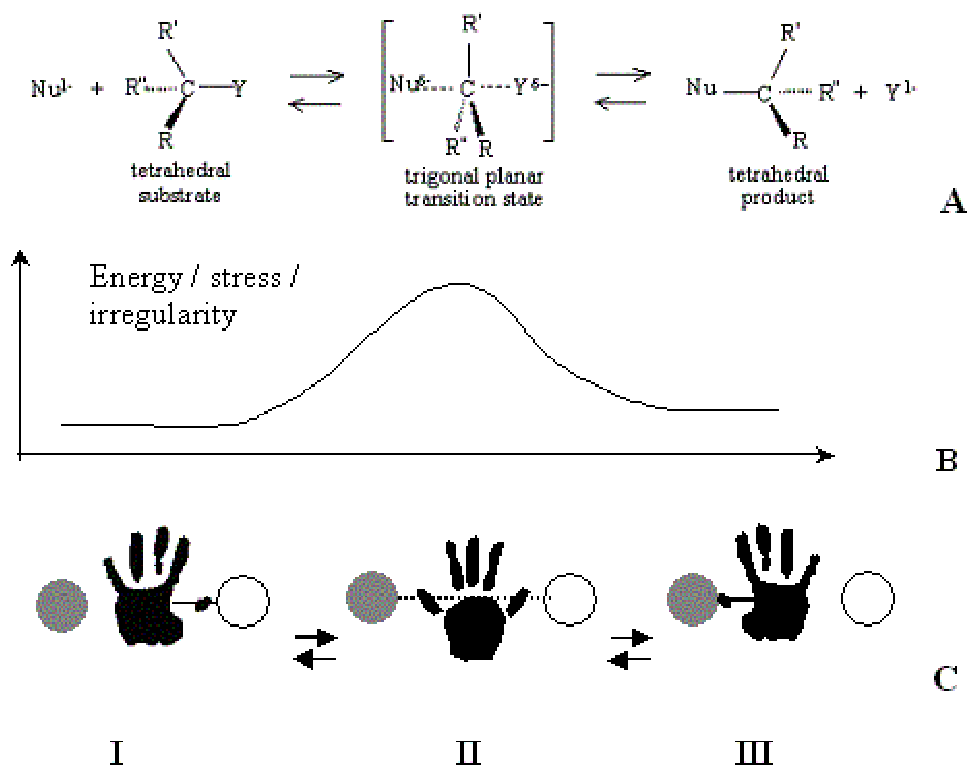


Figure 15.4 Substitution SN2

1. Except carbon **C**, no symbols of chemical elements can be seen. The symbols are of abstract nature, similarly to algebra and generative grammar. Symbols **Y**, **Nu** (nucleophil, negatively charged particle), **R**, **R'**, and **R''** stand for particular combinations of atoms. The superscript indexes 1– and δ – stand for a unit and fraction of negative charge, accordingly. Charged particles usually have a much higher energy / instability than neutral ones, but vary in stability among themselves. The double arrows $\rightleftharpoons$ symbolize the reversibility of the transformation: **I** $\rightleftharpoons$ **II** $\rightleftharpoons$ **III**. The stable states **I** and **III** are in an equilibrium with the transition state **II**.

Structures in **A** are 3D. The black wedges in **I** and **III** indicate that the bond is oriented toward the viewer and the broken wedges indicate the bond behind the plane of the drawing. All the other bonds lie in the plane.

2. The large square brackets around the transition state mean that it is in the process of change and is neither observable, nor stable.

3. Carbon normally has four valences, sometimes, two. The carbon atom in the transition state **II** has five bonds, two of which are shown by dotted lines to emphasize that they are irregular and temporary.

The middle part (**B**) visualizes the change of energy (stress, instability, irregularity) along the trajectory of the transformation. The initial and final states commonly (but not always) have somewhat different energy, so that the equilibrium is shifted toward the more stable state.

The lower row (**C**) is a 2D pictorial metaphor of what is going on during the 3D chemical transformation. All the events occur in the plane. The gray circle approaches the hand holding the white circle. In transition state **II**, the deformed (stressed, irregular) five-finger hand is in a precarious position, holding both circles. In the final state **III**, the hand holds the gray circle, but it is already a different hand.

The theory of transition state asserts that the speed of the transformation from one stable state to another decreases with the energy of the transition state. The latter forms a “barrier” that only molecules with sufficient energy can pass. Chemists use mostly the term **energy**, but the words **irregularity**, **stress**, and **deformation**, are also used in discussing regarding transition states.

The same transformation of substitution of Nu for Y, or one circle for the other can run through a different transition state, Figure 13.2 . It is known as **SN1**, Substitution Nucleophilic Monomolecular.

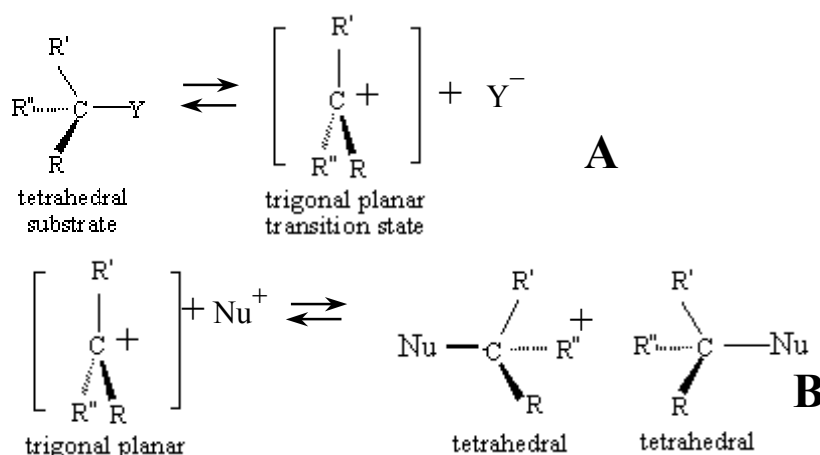


Figure 15.5 Substitution SN1

The initial state splits into Y⁻ and a crippled planar transition state with three bonds at the carbon atom (A). Next, the transition state can form a bond with either Y or Nu. Both can approach the transition state from either side of the plane. The 2D metaphor for this apparent mess is shown in Figure 12.3

We can start with either one of the four stable configurations outside the large square brackets. The four-finger palm can attach to either circle, which means that all four stable forms exist in an equilibrium.

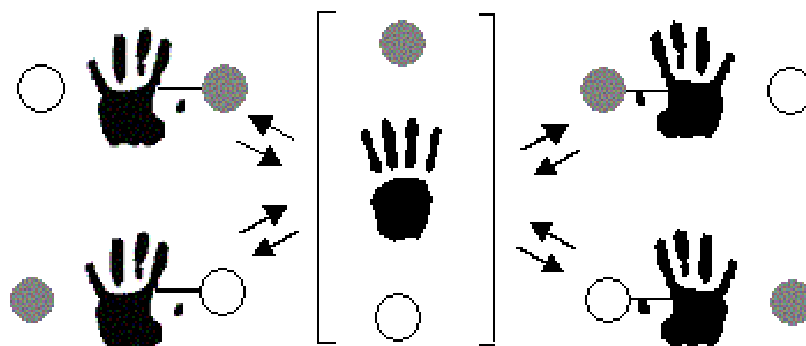


Figure 15.6 A metaphor of substitution SN1

Thus, the high energy transition states in **SN2** and **SN1** are irregular, unstable, and stressed because they are charged (in the eyes of a physicist) and have an abnormal number of bonds (in the eyes of a chemist).

Which mechanism takes place in reality depends on the part of reality which has been left out of the abstract picture: solvent, temperature, and the actual meaning of symbols Y , Nu , R , R' , and R'' . By studying the connection between the conditions of the transformation and its mechanism, chemistry acquired its modern theoretical sophistication even without observing the evasive transition state.

In short, the chemist who wants to predict or explain which alternative transformation will prevail in the short run, compares alternative transition states and gives the preference to the one with the less stressed (i.e., most probable) transition state. Generalizing this principle to the level of configurations in natural systems offers a new, **kinetic** approach to the dynamics of the complex systems built on the platform of life, including biological evolution itself, as well as border area between mind and society where language resides. The kinetic principle alone would do little good if not for another very general principal of natural complex systems, also inspired by chemistry: the change in any natural complex systems at any given time is mostly local. It means that most of complexity of the system is never involved in the change. This principle is well known to the historians of revolutions and, I believe, is applicable to language.

It is not accidentally that I selected human hands for a metaphor of substitution in chemistry. Molecules that, like hands, have no symmetry, possess chirality (handedness):

they are mirror reflection of each other. This property is of cardinal importance in biochemistry. The conclusions about the invisible transition states were drawn by chemists basing on the chirality of products. In **SN2**, a left-handed initial state reverses its chirality, while in **SN1**, the same state turns into a mixture of right and left final states.

A very similar method of oblique observations on utterances, leading to conclusions about unobservable thoughts, was first applied by no one but Sigmund Freud, a chemolinguist of a kind.

15.4 Program nean

```
% PROGRAM nean
% input: NN (number of cycles), score (total score), S, words
% example S      =[1 1 5 2 1; 2 2 5 2 2; 3 1 6 1 2; 4 3 5 2 2; 5 2 3 1 1;
% 6 4 5 1 2;7 1 4 1 2; 8 2 4 1 2; 9 1 3 1 2; 10 3 4 1 2];
% example: words= ['Ug   '; 'Og   '; 'bone '; 'cave '; 'give '; 'grim
%                  '];

LW=length(words(:,1)); LS=length(S(:,1)); LWS=LW-1;
E= 0;   A=[];
ns=0; %ns: number of selected strings
nw=0; %nw: number of different string in the output
tic
for n=1:NN;E2=0;
    p = randperm (LW); %random sequence of words
    DP=zeros(1,2);DS=zeros(1,2);
    E2=0;
    for i=1:LWS; DP=[p(i),p(i+1)]; %pair of neighboring words
        for j=1:LS %number of doublets

            SD=S(j, :, :); DS= [SD(2),SD(3)]; %pair of generators in memory
            DSR=[SD(3),SD(2)];

            if ((DS == DP) | ((S(j,5)==2) & (DSR==DP))), E2=E2+S(j,4);end ,
                %compared with the pair of G in permutations
                % score added to the total

        end
    end
    %if E2>E, E=E2; E
    if E2==score, p; A=cat(1,A,p);ns=ns+1; end
end,
n;A=unique(A,'rows');l=length(A(:,1));
W=[];
for w=1:l, W=A(w,:);WW=[];
```

```

    for v=1:LW,
        WW= cat(2,WW,words(W(v),:));
    end,
    disp([' ',WW]);nw=nw+1;
end
t=toc; t=t/60;
disp(' ');
disp([' number of cycles: NN = ',int2str(NN) , ' , run time: t='
,num2str(t,2), ' min, ' ]);
disp([' score= ', num2str(score,2), ', score matches ', int2str(ns), ',
number of different strings ', int2str(nw)]);

```

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Pattern Theory and “Poverty of Stimulus” argument in linguistics

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(2004)

Abstract

This paper continues the examination of language as a quasi-molecular system from the point of view of a chemist who happens to ask, “What if the words were atoms?” Any new word in the vocabulary must be at some time heard or read in order to be acquired. The new word practically always comes linked either with an observed image or with a few other words in a phrase or discourse, otherwise it would be meaningless at the first encounter. This halo of selective connections makes the morphemes and words recognizable as generators of Pattern Theory (Ulf Grenander), i.e., as atomic objects possessing a certain structure of potential bonds with preferences for binary coupling. In this way the word is typically acquired with a fragment of grammar. Metaphorically speaking, the generators of language carry bits of grammar on their bonds like the bees carry pollen on their feet. Regarding Pattern Theory as meta-theory for atoms and words, parallels between linguistics and chemistry are discussed.

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Introduction

The idea that children acquire their native language in spite of the lack of either direct instruction or sufficient number of correct or correcting samples goes back to Plato. Starting with this well seasoned “poverty of stimulus” premise, Noam Chomsky postulated the existence of an innate universal grammar (UG), and the entire theory became two postulates, one on the shoulders of the other. Further postulates about the nature of UG (for example, principles and parameters) had to be added to the increasingly unstable cheerleader pyramid, so that the issue became complicated and hotly debated. Any general course of linguistics, as well as the Web, reflects the war of the words over the tiny piece of intellectual land [1].

It seems strange that the problem of language acquisition exists at all. Language is a notation of thought. Then why is mastering notation separated from acquiring knowledge, logic, and mastering communication with the world? A possible reason is that we hear what children say but do not see what is going on in their minds. Circumventing this very large and complicated issue, I attempt to look at the bottom postulate of the disputed paradigm: the poverty of stimulus. This unaffiliated paper continues the examination of language as a quasi-molecular system from the point of view of a chemist who, inspired by Mark C. Baker [2], happens to ask, “what if the words were atoms?” The paper serves as an addendum to [3], without which some loose ends will hang in the air.

Speaking and writing is the manifestation of life we all engage into with visible and audible output. Why should a chemist's opinion matter more than anybody else's?

It is not universally remembered that chemists long ago invented, with the purpose of communication, the language of chemical nomenclature, which converts a non-linear object—molecular structure—into a string of words. The parallel between DNA and text was captured right at the birth of molecular biology. Chemistry and linguistics share much more conceptual genes [4].

Chemistry may be cool but linguistics is hot. I realize that there are very few original ideas in this paper, but to review even major domains of enormous linguistic literature is a hopeless task. Philosophic literature on the subject, from Plato to Wittgenstein, would alone sink my ship still in the harbor. Many references are omitted, especially, when ideas have been popularized and are widely spread. Leading modern linguists (some are mentioned in [3]), write about language with gripping virtuosity and passion (Examples: [9, 19]).

There are good reasons why the linguistic literature easily overwhelms the chemist used to the enormity of the chemical literature, and, I suspect, even linguists themselves.

First, modern linguistics is far from the habitual for chemistry consensus. Second, linguistics, is still very far from reproducing the human ability of rational communication, contrasting with the triumph of applied chemistry which can identify (“see”) and reproduce (“say”) any substance from scratch. Third, many linguists examine language in terms of language, while chemists examine molecules in terms of their graphic images and measurable properties, using an absolute minimum of words.

While many linguists appeal to the jury for a verdict beyond reasonable doubt, the chemists require a hard proof beyond any doubt. Amazingly, both deal with real and observable objects, which alone should clear the way for linguistics into the family of natural sciences. Moreover, molecules are invisible without instrumentation, while words can be heard and seen even by small children.

I have no intention to snicker at linguistics. On the contrary, I intend to lovingly poke fun at the heavy, Puritan , tedious, and down-to-earth realism of my native chemical thinking.

The chemist works like the farmer and proves his point by bringing a molecule or process to reproducible material existence, as if it were a pumpkin. This is, probably, too much of virtue for the flowery, fluid, sybaritic, and Bohemian habits of language speakers and tillers. But what can you expect from those who deal with mindless and speechless molecules? Even cows moo. And yet I think chemistry is one of two most romantic sciences on Earth. The other one is linguistics.

Coming from a non-linguist, the opinion expressed here cannot be an argument in a professional discussion. It might, however, illuminate the problem from a new angle for both professionals and fans. Chemists think about the world in very distinctive terms. To demonstrate this is my major goal and part of a larger program, see [4, 5]. I am interested in the export of chemical experience to cognitive and social sciences with Pattern Theory as meta-theory for all discrete complex combinatorial systems.

As for my own language, which is not my native, I will use, with the ecumenical blessing of George Lakoff [6, 7], metaphors with all the self-indulgence of somebody in no need of a grant.

All unfamiliar to non-linguists terms could be easily found on the Web.

1. Sets and order

If I asked only the question “*what if the words were atoms*” and stopped there, the answer would not go beyond a metaphor. When Mark C. Baker entitles his enjoyable book “*The Atoms of Language*,” he assumes that there is more to words than their use as building blocks of a combinatorial Lego. I am going to encourage the timid interplay of two distant but related disciplines by asking the inverted question: “*what if atoms were words?*” I believe that both questions are equally legitimate. They will guide us toward the realm of complex discrete combinatorial systems, which is still a little explored pre-Magellan world where administration and legislation overrides navigation.

Pattern Theory is the first system of mapping which shows Linguarectica and Chemistralia as recognizable continents made of the same firm land and surrounded by the same ocean. In Pattern Theory (PT), both words of language and atoms of chemistry are **generators** and their deep kinship is more than just a metaphor. The best way is to go to *Elements of Pattern Theory* by Ulf Grenander [8], which carries a great inventory of seeds and fertilizers for intellectual farmers. Next I will try to approach some of the basic ideas of Pattern Theory through the back door where ID is not asked and nobody cares whether you are chemist, linguist, or just a chatterbox.

The most fundamental and unifying concept of mathematics is **set**: any collection of any elements which can be combined and recombined into new sets. Elements of the set have nothing but pure identities. Thus, from elements **A**, **B**, and **C** we can form sets **{A}**, **{B}**, **{C}**, **{A, B}**, **{A, C}**, **{B, C}**, **{A, B, C}**, and empty set **{Ø}**.

The **mental** operation of combination is **unconstrained**, requires **no effort**, and the order and relation of elements in a set **do not matter**. There are no ties of any kind between the elements of a set except for being thrown together between the brackets. Set elements can be compared to pieces of paper with names, thrown in a bag and offered for drawing a lot.

In casting a vote, when a number of voters place their ballots, some of them identical, we deal with the **multiset** (also called **bag** in computer science), for example, **{A, A, B, C, C, C}**, where order does not matter either.

Strictly speaking, chemistry deals with multisets, so that when molecule **A** turns into **B**, there is still plenty of **A** around. This is not so in computers and the mind, where everything is represented in single copy, so that any destruction is irreversible. The analogy with chemistry, however, becomes striking if we note the function of memory: whatever happens, memory keeps hard copies, at least for a while, and so creates an effect of multiplicity.

A list of names in **alphabetical order** is a quite different object. The elements of the list cannot line up freely. They must stick together in a certain way defined by their **local** properties, namely, their first and subsequent letters compared with an arbitrary **global** alphabet: **A, B, C ...Z**. The alphabet is just a mapping—one symbol to one

number—of the set of positive integers on the set of symbols. Such sets are **ordered**: for each two elements, one precedes the other.

There are also partially ordered sets (**posets**), like the somewhat flexible list of our daily priorities or the hesitant subjective rating of beauty contestants. In such sets we are certain about the order of some but not all pairs of elements.

2. Laws of grammar and laws of nature

Suppose we collect a large number (**corpus**) of actually spoken and not just possible utterances and have to decide which are **correct** (grammatical, *lawful*) and which are not. This task is easy if we have clear criteria of correctness, or at least a corpus of definitive correct utterances. But what if the language purists are split on the subject and, moreover, the speakers do not listen to them? Then a possible solution is to select a sub-corpus of statistically most frequent variations with the same meaning and regard them as the standard against which irregularities could be measured. The purists may not agree with some entries, but they will be certainly satisfied with most of them. Some people, however, may disagree about meaning. Besides, spoken language is largely automatic, improvised, and heavily dependent on context, intonation, and facial expression.

My point is that the notion of correctness is like the survival of the fittest in biology: it is circular and, therefore, just a mental toy.

Note that the real man-made lists can have irregularities and the number of deviations from the alphabetical order per a unit of length could be an overall measure of the irregularity. For large collections of linear sequences (strings) of elements, whether speech, texts or DNA, a metrics, like Hamming distance, can be established: the sequences differing in one element are closer than the sequences with two discrepancies. This can be generalized for any complex objects. This is how a natural statistical norm can be captured. Statistics is not the only instrument of the linguist comparable with the

heavy duty instrumentation of the chemist. There are probes and tests very similar to chemical ones, like the wug-test.

My intent in probing the laws of grammar is to compare them with the laws of physics and chemistry. There is no correctness or incorrectness in nature, to which language belongs. This is why the very idea of a natural grammar as a system of rules and parameters, or just rewrite rules, stored in the mind of a little child and not in a book or an adult mind, seems to me, a chemist, as unnatural as any alphabet.

Let us turn from artificial (mind-driven) to natural (mindless) processes without external human control, which we understand much better than human matters.

The atoms stick together for physical reasons and form more or less stable aggregates called molecules where the number and order of connections of the atoms of different kind have a decisive bearing on the individuality and **behavior** of the molecule. If the atoms were indeed words, we could say that the atoms could form some stable aggregates and resist forming some others because **they knew the grammar** (i.e., rules and parameters) of chemistry.

Atoms do not consult the textbook of chemistry, however, before assembling into aspirin. The possibly enlightening for a linguist chemical story is that they “know” the rules in a noteworthy manner: **given indefinite time**, the molecules assemble in such a way, that the aggregates with the lowest energy are much more abundant than those a notch up on the scale. This is the only universal natural rule, but there is a multitude of not rules, but **properties** of atoms, which define the actual form of the aggregates. There is a wide-spread among linguists belief that language has an infinite generating power (Chomsky: ”discrete infinity”), but chemists are more cool-headed. Theoretically, all possible assemblies of a given set of atoms will be present after an indefinite time, but only a few will be **in fact detectable**, and even less will be prevalent. Should we say that the minor versions are wrong?

Chemists, like businessmen, are not interested in indefinite time and they focus on the problem of relative speed of alternative concurrent transformations. The concept of transition state, i.e., the bottleneck of transformation, is the major, but still neglected,

contribution of chemistry to the theory of complex systems. More about that, see [5, 4, 3]. This, however, has little to do with language acquisition because the time of individual learning is negligible with the time of language genesis and evolution.

Molecules **behave** because of the inherent molecular motion. Any living, not pinned to the display box, language is also full of motion: utterances fly around, clash, and scatter the sparks of fragments, not to mention processes on the historical scale. There are especially hot areas of professional, sub-cultural, and child language where new mutants are born to survive or die. Some parts of everything that has been **really** said and written during the day settle down in written or recorded form and can be used to study the language variations and evolution in the same way a paleontologist studies the evolution of birds. Alas, not much was left before writing, but tribal languages store a lot.

Language, which comes in populations and perpetuates by replication, mutation, and exchange of material, is a form of generalized life. Contrived examples are chimeras. Remarkably, chemists sometimes start with chimeras in their imagination and then successfully synthesize them and even use for practical purposes, as nanotubes illustrate, but one cannot learn chemistry from nanotubes alone.

Molecular systems and language are similar not only because they consist of atoms, but because they are natural dynamical systems driven by the constraints of **thermodynamics**. This reeking of hot engine oil term means, in fact, something very general and simple: there is a preferred direction of natural events, and we know what it is, and if we go against it, we have to pay a price in the currency of energy. Natural language is not an exception and this is why it is **always correct**, until some shock hits the society of speakers and the language finds itself in an uncomfortable **unstable** position on the hill slope and slides toward a new position of reduced social stress, as the preferred direction of natural events requires. The preferred direction of language evolution, recapitulated in individual language acquisition, is the optimization of communication as part of social life. This is how a chemist could paraphrase the perfectly natural idea that language is an adaptation (Steven Pinker in [9] and earlier with Bloom),

although evolutionary thermodynamics of the open systems, like life and society, is today formulated only in very general terms. An eloquent, I would say, beautiful discussion of the subject in non-chemical terms can be found in [9], where even the distant behind-the-scene voice of chemistry can be heard (Komarova and Nowak, in [9]).

My opinion of an outsider is that truly systemic linguistics should treat language as a natural system with a generalized physics, chemistry, and even physiology. A similar direction was outlined by Christian Matthiessen and M. A. K. Halliday: “It [language] is a phenomenon that can be studied, just like light, physical motion, the human body, and decision-making processes in bureaucracies; and just as in the case of these and other phenomena under study, we need theory in order to interpret it” [10]. In [3] I put Joseph Greenberg and Noam Chomsky in the opposite corners of the linguistics Hall of Fame. Today I see, alongside Greenberg, Brian MacWinney [11], who works with language as a typical natural scientist.

3. From sets to generators

There are more probable (and, therefore, more stable—thermodynamics again) and less probable (and, therefore, less stable) molecules, which are sets of atoms under various constraints. Some atoms in a molecule are bonded, others are not, and the bonds have different properties.

The mathematical image of molecular structure is a **graph** in which atoms are points selectively connected with lines. In a simple graph, the positions of the points (**nodes**) do not matter and all the connections (**arcs**) are the same. In the colored graphs the arcs, and in the labeled graphs the nodes, can be different, which makes them suitable to portray molecular structure. In a real molecule, atoms commonly oscillate around fixed positions in 3D space.

Only a few molecules are linear, but linear polymers, for example, DNA, consisting of molecular blocks arranged like the words in a text, are the most conspicuous evidence of the mathematical kinship between language and chemistry, well recognized by both clans.

Figure 1 shows a few objects that can be obtained from simple sets by adding binary relations between elements. Some elements are circles with different fill patterns, to emphasize their individuality. Sets with connected elements represent what chemists and architects understand by **structure**.

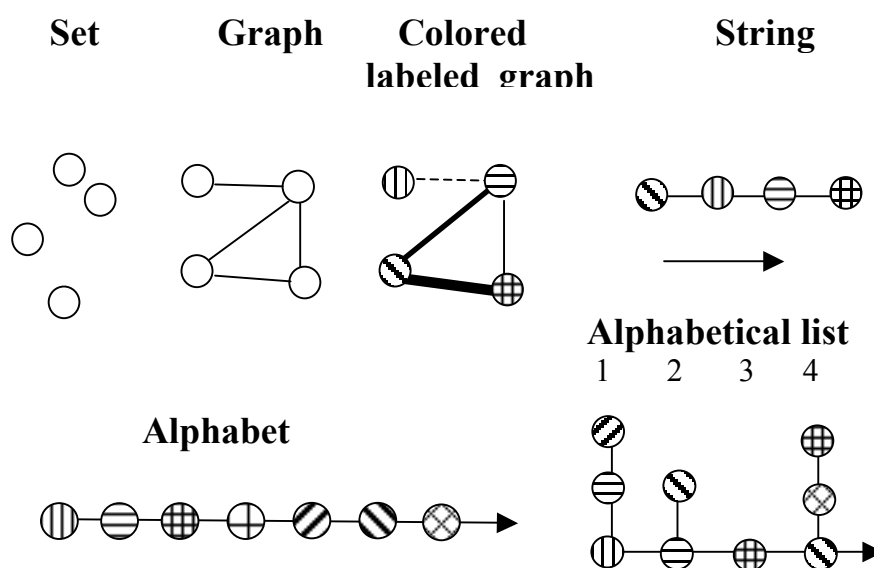


Figure 1. Evolution of sets

The concept of **mathematical structure** is something different. In a way, an ideal grammar is a mathematical structure: it separates right from wrong. Mathematical structure, simplistically, consists of terms, axioms, and operations, so that one can say which result of operations is right and which is wrong. **Algebraic structures** are a set of elements, a list of axioms, and one or more operations that turn two elements into a third. Obviously, this is what chemistry and linguistic do by connecting one block with another. This is why algebraic structures are in the foundation of mathematical linguistics [12]. The belief in the infinite language, probably, feeds on the computational idea of language as an obviously infinite set of strings generated by the operation of concatenation.

Generators and configurations also form an algebraic structure. From this point of view, algebraic structure and “structural” structure conceptually converge: it is all about binary operations. Chemical structures, however, have a lot of additional physical constraints that are beyond algebra.

Let us take an alphabetical arrangement: **LIST** = Andy—Bob—Pat—Ronny—Zelda. It is ordered according to the Latin alphabet:

A	1	...	Q	17		
B	2	O	15	R	18	Z 26
C	3	P	16	S	19	

LIST is a very simple artificial object, a result of my mental activity. *If the words were atoms*, it would be reasonable to ask how **LIST** could originate from names without human participation.

We can describe the petite **LIST** in deceptively complex terms as a **configuration** of elemental objects: **generators** g from the generator space **G**. Generators are a kind of abstract atoms that can self-assemble, at least in our mind, into regular (*lawful*) configurations. Two examples of are shown in Figure 2.

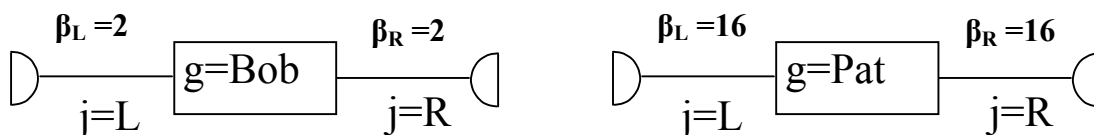


Figure 2. Generators of LIST

Each of the objects has an identifier g , i.e., label (name) and two bonds with coordinates j , labeled as L(ef) and R(ight). The bonds have numerical bond values β which are simply the positions of the first letter of the name in the alphabet. It would be reasonable, however inconvenient, to index β and j with the generator name:

$$\beta_L^{\text{Bob}}, j_R^{\text{Pat}}.$$

Let us apply the following rules to the **behavior** of these objects:

For g_1 and g_2 , $\{g_1, g_2\} \subset G$ (i.e., for two generators from space G)

$$\rho = \text{TRUE} \quad \text{if} \quad \beta_L^{g_2} > \beta_R^{g_1}$$

Here we have the bond relation ρ that depends on the bond values β of two generators g . If $\rho = \text{TRUE}$, the two generators can be neighbors in the list. If **FALSE**, they are not fit to rub shoulders.

Note the **local** character of the rule. In order to check a compliance with the rule, only an examination within a tiny area of the string is necessary. The entire “behavior” of generators is local: the events consisting of acts of locking and unlocking (no, words *local* and *lock* have different origin) do not happen at a distance. Otherwise it would require a homunculus to control it. This property is important for any process of genesis of a complex system without a complex controlling mind. *Natura non facit saltum*, from this viewpoint, means that nature has neither mind nor algorithm, nor Random Access Memory to romp around all over. We can safely assume that humans started the language from scratch and were not taught by other beings how to deal, for example, with anaphora, i.e., the mental jump from the noun to its respective pronoun and back while we speak. It is only natural that humans are teaching the computers with RAM and ROM to do this trick and not to be lost in multiple nouns and pronouns. The simpleminded children acquire their simple pre-school language **without a tutor** because the acts of acquisition are local and, therefore, do not require a thinking mind. Later they start to chew on the bitter roots out of which the minds grow.

The word **behavior** adds a flavor of spontaneous activity to generators.

Metaphorically speaking, we take a handful of generators g from the bag G and shake them in a box, so that they could stick to (or repel) each other according to their preferences, like the frequenters of a singles bar, only somewhat kinkier. Note, that

neither algorithm nor human control is needed for the spontaneous self-assembly of the above generators into a string—nothing but some random “shaking.” We have to supply motion as the source of chaos, but a series of earthquakes over a million years would be as good for the purpose of shaking a box.

The physical flavor that I attribute to generators is not to be found in Pattern Theory, although it can be easily inferred. I am taking some chemical liberties with mathematics. Nevertheless, in some sense, defined in PT, generators selectively **accept** (or **repel**, I would add) each other with varying enthusiasm. There is an **acceptor function** for the mutual affinity of two generators.

In a more general case, the bond value can be any number, regardless of any alphabet, and ρ could be a function of the two contacting β , so that for some pairs (bond couples) ρ is high (i.e., very true) and for others low or negligible (i.e., very false). Not only that, but probabilities or additive **weights** (not related to connectionist learning) can be attributed to the generators themselves, as in topicalization, i.e., putting the most important word first (fronting), and marking it either vocally or, in languages like Japanese, with a morpheme, in addition to fronting.

Finally, we would be able to calculate the probabilities of a string of symbols or a list of names by multiplying the probabilities of bond couples and the “weight” of names. We can also express the mutual affinity of generators and their weight in terms of generalized **energy**, which, unlike probability, is additive over the increments of bond couples. As result, we arrive to a kind of generalized chemistry of symbols, if not of everything. In PT it is called Pattern Synthesis.

Pattern Theory is about probabilities on structures. The system of this kind generates **thoughts** in Ulf Grenander’s GOLEM [13], which, in my view, is an initial model of meta-chemistry where generators combine into configurations under predominantly local rules.

To make the next step toward PT, we need to further generalize generator by lifting the limit on the number of bonds and allowing non-linear configurations. They are

never present in speech, but nobody has ever managed to do syntax or semantics without either a tree or a Russian doll of brackets.

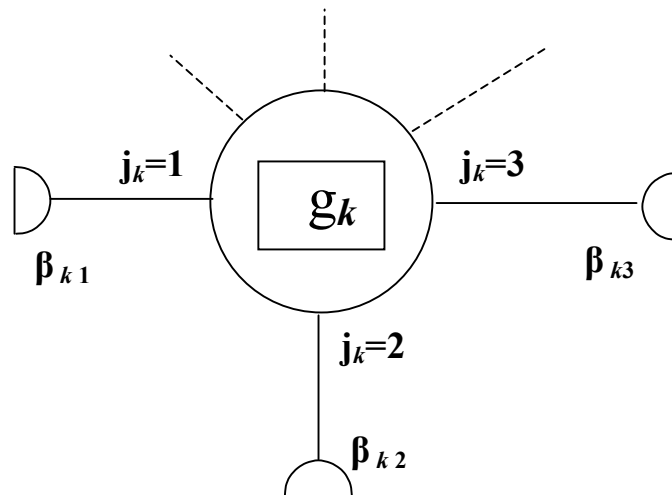


Figure 3. “Generic” generator

A generic portrait of an atom of everything is presented in **Figure 3**. It can have more than two bonds and can form a great variety of configurations, typically, non-linear. Abundant illustrations from large number of areas of knowledge can be found in [8] and more special and technical works in PT, where numerous shapes are analyzed and produced from a generator space and a minimum or no global constraints.

4. Patterns

The last key step from configurations to patterns is simple: pattern is a class of configurations. In PT it is a **similarity transformation** that generates one configuration from another within the same class. **Regularity** of a configuration, which plays the role of mathematical structure axioms, consists of generator space G , bond relations ρ ,

similarity transformation S , and the type of connector Σ , for example, LINEAR or TREE . Regularity can be strict or relaxed.

Since major applications of Pattern Theory are designed for processing two-dimensional images, similarity transformations can often be expressed analytically in the form of equations, for example, for stretching, rotation, warping, etc. , or by non-trivial algorithms. In the discrete space of linguistics this is hardly possible. A similarity transformation can be simply a change of the word within a logical, morphological, syntactical, or, as in poetry, just phonetic category. The prototype of all similarity transformations in linguistics is the Laputian machine, witnessed by Gulliver, in which letters were permuted at random to produce a word of new knowledge.

Another way to describe the pattern is to formulate not what the similarity transformation changes but what it leaves unchanged.

Because of the historical origin of language patterns, it is not always possible to explicitly formulate the similarity transformation and it can be defined as just a list. Languages with genders (Russian, German) and noun categories (Bantu group) are of this type. What seems a logical aberration, like the neutral gender of **girl** in German (das Mädchen) must be just memorized by rote. There must be some evolutionary logic.

An interesting channel opens between PT and the domain of categorization in linguistics, with theory of prototypes (Eleanor Rosch [14]), inspired by Ludwig Wittgenstein's concept of family resemblances. The **template** of PT, which is a **typical** configuration, seems to be the exact counterpart of the prototype in linguistics. Pattern Theory was also inspired by Wittgenstein. The realistic aspirations of systemic and cognitive linguistics echo the realistic spirit of PT, still missing, as it seems, the heart of the matter with all natural systems: measure.

Since I am interested here only in what is necessary to test the Poverty of Stimulus Argument, I shall refer the reader to PT for more detail. I have only a few strictly personal remarks to be made on part of a chemist and not-mathematician.

A generator space $\mathbf{G}$, i.e., a set of generators with their properties, defines a combinatorial configuration space $\mathbf{C}_G$. Formally, it does the same job as the Cartesian coordinate system, which defines all possible points of Euclidean space, or the Chomskian principles and parameters, which, ideally, define all possible grammars, or the questions of the US Census, which define the essential profile of the US population. It does the job, however, without any explicit **global** list of coordinates for the multidimensional spaces, but by providing strictly **local** descriptions of generators and allowing some freedom of their mating.

We can use this curious system of coordinates, so practical for immaterial discrete systems in non-Euclidean spaces, if we tacitly count on the mystic ability of generators to find each other and stick together the right way or one among many right ways, some of them more right than others. This is a kind of mathematics that has some properties of physics and chemistry. This is how I became enthralled by PT. It is potentially a calculus of all **realistic** (however immaterial) **discrete** combinatorial objects because it attributes *a priori* some probability to their existence. It predicts what is **likely** to happen and explains why other alternatives are less likely.

In the case of alphabetic lists, the all-or-nothing system of rules defines all possible alphabetic lists and separates them from even larger space of all non-alphabetic ones.

In general case, Pattern Theory can partition the set of all configurations into regular (by the rules) and irregular ones, but even more generally, it offers a measure of regularity on a continuous scale.

The connection with linguistics can be seen here. Not only are grammatical structures regular and ungrammatical ones irregular, but some are more regular than others and others are less irregular. Moreover, there is a measure of stability, and some constructs are more stable—less ambiguous or difficult to understand—than others, provided the content of the mind is the same. Benjamin Worf's idea, as I understand (or misunderstand) it, was a relation between language and the content of the mind, which is defined at least partly by the environment.

Here are two color-coded examples. Examples are from [15]

The lines mean:

1. A Hungarian phrase.
2. The Hungarian phrase segmented into morphemes.
3. My interpretation, in a kind of pidgin, of the meaningful words and morphemes.

The colors match the first line.

4. Linguistic glosses, i.e. meanings of words and morphemes, using abbreviations.
5. English translation
6. Literal translation

Example 1

1. A szobában ülő gyerekek játszanak
2. a szobá-ban ül-ő gyerek-ek játsza-nak
3. the ROOM-in_it SIT-doing CHILD-many_of_them PLAY-they_do
4. the room-INNESS sit-PRSPART child-PL play-3PL
5. 'The children sitting in the room are playing.'
6. Literally: The in-room-sitting children play.

Example 2

1. A gyerekek a szobában ülve játszanak
2. a gyerek-ek a szobá-ban ül-ve játsza-nak
3. the CHILD-many_of_them the ROOM-in_it SIT-while_doing PLAY-they_do
4. the child-PL the room-INNESS sit-VERBADV play-3PL
5. 'The children are playing sitting in the room.'
6. Literally: The children, in the room sitting, play.

I bet most readers can understand almost any Hungarian phrase presented like the third line. Moreover, any language can be understood in the same way. This property of language is the basis for of automatic translation. I added line 6 in order to be as close to the Hungarian text as possible, even at the cost of “correctness.” Yet the correspondence between the phrases is somewhat loose. There is only one definite article a in the first example, but two the in the English translation. The Hungarian text does not give a clue regarding the English tense, because there are only Past and non-Past tense markers in Hungarian verbs. The Hungarian continuous tense is extinct. Instead, Hungarian has a number of verb forms untranslatable into English directly.

Both examples, honestly, mean the same and can be expressed in both languages also in other ways, e.g., “The children are sitting in the room and playing”.

We understand the sentence in Hungarian or Japanese, if translated into an artificial inter-language, because it describes a situation with which both Americans and Hungarians are familiar. A phrase from a textbook of microbiology would not be universally understood. Our language is **embodied** (George Lakoff) in our human existence.

I have not discovered either America or Hungary with my examples. This subject has been intensely discussed in linguistics. I would formulate it this way: the patterns of thinking are universal because their invisible generators are identical, but the patterns of language are different because their visible generators are different. We master both because we acquire the generators bit by bit and this is all we need. Our mind is a flask where they assemble and our mouth pours them out. The ready patterns of adult and peer speech catalyze some patterns of children at the expense of others. But we pick the generators from different fields and they could be different berries altogether.

As I suggested in [2], not claiming any revolutionary insight either, because this is the very essence of language, the configuration of the internal source of the utterance is commonly non-linear and it must be linearized, sometimes in a tortuous way, to be verbalized. This where I see the essence of universal grammar, and as any essence it is utterly simple.

In terms of Pattern Theory, grammar is a collection of regular (not correct!) patterns of word/morpheme configurations. From this angle, UG is, most probably, just the innate ability of humans and animals to perform pattern analysis and synthesis, demonstrated not only in language but also in locomotion, perception, hunt, work, dance, rituals, play, investigation, politics, etc. The uniqueness of human language acquisition device, however, is undeniable. The speaking mind has to convert the nonlinear content into a linear message at one end of communication channel and reconstruct the content at the other end—a far cry from learning to dance or bake pizza by just watching how it is done and repeating the motions in the Euclidean space.

It is my personal impression that PT plays the role of mathematical physics of complex combinatorial systems to which all chemistry and manifestations of life on earth from the life of a cell to society belong. In this area not only deterministic equations are usually powerless but even the probabilistic theories get stuck in the mud for a simple reason: in evolution and history every global (defining) event is unique. It does not belong to a statistical ensemble, while local events do. It can be comfortably viewed, however, in local terms of breaking and interlocking bonds, which is the area of expertise of chemistry.

So much for the kinship of chemistry and linguistics. What about linguistics and biology? Speaking not as a chemist but as an adventurer, I would say that the language in the form of the second or third lines of the above examples is, in my opinion, the closest we can have approximation to the most ancient pattern of tribal languages, well after Nean. As we had lost our tail and are now losing classical music, so English lost its cases, Hungarian lost its Present Continuous, and Russian its vocative case.

What they all acquired was a great syntactic complexity of compound sentences to describe complex ideas, situations, or just to show off, as is proper for a performance art such as circus.

With similar experience, we will understand each other whether we say

ROOM-in_it SIT-doing CHILD-many_of_them PLAY-they_do, or
CHILD-many_of_them PLAY-they_do SIT-doing ROOM-in_it , or
many_of_them-CHILD they_do-PLAY SIT-doing in_it-ROOM-in .

Moreover, unless our life experience is radically different, we will understand each other even in Nean [2]:

child! child play! child sit! sit room! play sit !
child! child room! play child! play room!

I have an impression that we encounter difficulties with automatic translation not because the problem itself is complicated, but because our civilization is a real mess. What do you think the words *universe*, *magma*, *ring*, *loop*, *variety*, *envelope*, and *signature* mean? They all are mathematical terms. *Atom* and *molecule* are terms of propositional logic. I suspect that tribal languages in their traditional pre-technological forms are the easiest to cross-translate if the subject is traditional, too.

5. Notes on notation

Formalization in chemistry is of little value. The rules of the chemical grammar can be easier described than formalized, especially, for a chemist.

I have a subtle grudge against mathematical formalism in its dominating form: it is based on the axiom of closure, which, coming from the Aristotelian requirement of the permanence of the subject, means that the set of terms during the discourse remains unchanged. It efficiently eliminates any ability of mathematics to formalize the phenomenon of novelty and evolutionary invention. As far as I know, only Bourbaki [16]

in the concept of the scale of sets attempted to cover, albeit in a skeletal way, the unusual subject of novelty and, therefore, evolution. Acquisition is a particular case of evolution. How can you acquire something that is already in your bag? Until I am seriously rebuffed by a mathematician, I swear never to miss a chance of drawing attention to it.

Although my aim here is to outline some ideas in an informal manner, a notation can help clarify them and to show how language is truly embodied in reality and what chemists mean when they speak their lingo.

I use figure brackets and three other kinds of symbols: letters, simple lines, and special arrows $\Rightarrow$ or $\Leftrightarrow$. The letters can signify sound, word, phrase, sensation, image, trace in memory, idea, etc. The lines are binary relations (if directed, the line turns into a simple arrow), and the special arrows mean causation. The signs, including the brackets, suggest, in sufficiently vague terms, that we deal with real world objects and processes displaying in real time and topological space. The underlying nature of these processes is completely beyond the scope of the current discourse. The chemical parallels, however, are clear: letter is an atomic object, line or arrow is a bond, and the special arrow is a transformation. Symbols of chemical reaction $\rightarrow$ and $\rightleftharpoons$ are the verbs of the chemical language, if you will, and $\Rightarrow$ and $\Leftrightarrow$, which I use outside chemistry, are also verbs of a kind. As I will try to show, the chemical formalism, while reflecting chemical ideas, points to much more general concepts, rising some strange questions that never bother either mathematicians or linguists or computer scientists.

$\{A,B\}$ means not just the set with two elements, **A** and **B**. This is more like a topological neighborhood: the elements of the same set in some sense are **close** in space or time. More specifically, the two elements appear together in some situation. In case of language acquisition, $\{A,B\}$ means that **A** and **B** are words, objects, or traces in memory perceived or recalled within a relatively short span of attention. They are, so to speak, pushed by chance or intent to face each other—a common thing in psychology and neurophysiology. In case of a chemical process, they are on collision or within a close spatial range or just are dashing around in the same flask, of course, not without the chemist's hand in it.

$A\text{---}B$ means that elements A and B are **bonded**. AB means the same.

$A\rightarrow B$ may denote a directed bond, which we find in configurations of thought and many chemical bonds.

$$\{A, B\} \subset G, \quad \{A, B\} \Rightarrow AB, \quad AB \Rightarrow C, \quad \{A, B, C\} \subset G,$$

means a chain of transformations leading to the expansion—this is synonymous with acquisition—of the generator space G . First, A, B , elements of G , brought together, lock the bond AB . Configuration AB generates a new element C , which also enters G as a generator. C is the sign that denotes doublet AB and it can be used instead of it. This relation is reversible: $AB \Leftrightarrow C$.

This is the tricky point where the strange questions arise. For support I can only turn to the authority of Bourbaki, who builds the scale of sets in this way. Nothing like that can really happen in nature, where matter has no double existence, but is natural in the mind. **The mind is the second existence of the world and the language is the second existence of the mind.** When we talk about really profound subjects, things are never completely clear and, as Niels Bohr once noted, opposite statements are both true. Only a chemist can confidently say that A and B **reversibly** combine into a very stable C , which does not exclude the existence of free A and B . For the chemist, AB and C are **in equilibrium**. For the rest, it is just a far-fetching metaphor. In cognition, however, we can find a more sympathetic reception: C is a **sign** of the **category** to which AB belongs. When we think about **cats** and **dogs**, **pets** are kept in mind, and if we think about **pets**, both **cats** and **dogs** pop up.

In PT we are like fish in water: C is the identifier of a composite generator. Two bonded generators (doublet AB) can be regarded as a new generator and assigned a separate symbol (C), which does not erase either A or B from generator space. The bonds of C are whatever free bonds are left after AB is bolted together.

We could spend a lot of time hairsplitting over the relation between set theory and Pattern Theory, mathematics and the world, theory of meaning, but I am least of all qualified to do it. What we are talking about is a very generic and universal thing: the hierarchy of building blocks, with which linguists, chemists, and engineers deal every day. The existence of dining tables is no threat to the existence of either the table boards or the legs in the inventories and storages. The existence of grammar does not jeopardize the prosperity of either syntax or morphology.

The chemists practically always deal with multisets in the sense that atoms and molecules are present in enormous number of copies. I believe that the ability to build a hierarchy of signs is as profound property of mind as physical aggregation is a property of matter, but symbols, signs, and shortcuts do not belong to matter. This is how I would formulate the strange problem, which a mathematician could, probably, clarify: is the scale of sets or, to take a simpler example, the set of all subsets (**power set**) a multiset? If yes, then there is a non-trivial set which is also a non-trivial multiset. If no, then any set of sets is always their union. All I could find was that obvious statement that the power set of multisets is a multiset and that in computer science it is convenient to regard a power set a multiset, but the references were not reliable.

In connection with the strange problem, I would refer to memory—the crucial part of cognition and, more generally, life. Mathematics and the universal Turing machine assume an infinite memory. We recognize and/or memorize NEW and recognize or forget OLD. In human mind, if we do not use $\{A, B\}$ anymore, it is forgotten, but C can remain, and *vice versa*.

Formally, $AB \Rightarrow C$ reminds the composite arrow of **category theory** (CT) [10], which exerts an unclear to me and some others influence on linguistics, starting with Chomsky. Generators, obviously, are different mathematical objects, but both objects are associative.

I am determined to shun any discussion of what the terms **close**, **appear**, **bond**, **stability**, **reasonable**, **result**, etc., could mean: their meanings follow from their use, as

Wittgenstein believed, and this is why we, humans, sometimes cannot understand each other. What is important, all such terms can have measures. If close, one can ask, then how close? If something is stable, than is this more stable than another? If it results, transforms, or appears, then how fast? To ask such questions is a deeply ingrained habit of the chemist and the natural scientist in general. The remarkable aspect of PT is the ability to provide the framework for answering them regardless of the particular subject. Thus, approaching a speech generation problem from this typically chemical angle, we might decide that not the most grammatically and semantically correct, but **the fastest to generate** utterance will be produced and, probably understood in context. Similarly, in the social and political matters, not the most reasonable in the long run but the easiest to implement decisions are most often taken, falling into the range from symbolic to violent actions.

To conclude this session of a self-examination of the chemical mind, I would like to touch the evolutionary nerve of a chemist.

While the general principles of evolution are a separate topic, far from consensus and not to be discussed here, the chemist's view of evolution is more settled. It shapes the overall chemical attitude toward building any complex system. In a few words, in the style of *Poor Richard's Almanack*, it is as follows.

1. Easy does it. Complex systems are built from the simple ones in simple steps.

This is the most axiomatic statement from which the other two are partly deducible.

2. Rome wasn't built in a day. Therefore (see 1), the building of a complex system starts from a simple system.

3. Do not change horses in the middle of the stream. The steps are similar

throughout the evolution because when the step is simple (see 1), there is not much margin for variation.

In Poor Richard's words, "Haste makes waste," which is, actually, a nice definition of generalized temperature.

From the PT standpoint, which is directly translatable into the chemical mindset, the acquisition of language consists of pattern analysis of speech, i.e., identification of generators, partition of generator space into classes, and selection of **stable** (regular) patterns that partition the configuration space. What is called Pattern Synthesis is the actual production of configurations, which is of no interest for us here, but should be for those working in speech generation.

The steps will be described below. The reader should keep in mind that this is not a linguistic discourse but just a series of variations on the theme of "***If words were atoms.***"

6. Bonding

The concept of atomism is usually presented to schoolchildren as the granular structure of matter, but Lucretius, following Democritus, saw in bonding an intrinsic property of atoms:

But now
Because the **fastenings** of primordial parts
Are put together diversely and stuff
Is everlasting, things abide the same
Unhurt and sure, until some power comes on
Strong to destroy the warp and woof of each:
Nothing returns to naught; but all return
At their collapse to primal forms of stuff.

(*On the Nature of Things*)

Chemical bond is well understood today. Formation of a bond, however, is a very general property of the world, extending far beyond the inanimate matter. Bonding, of which both Pavlov's dog, salivating at the sound of the bell, and the inseparable Romeo and Juliet are two quintessential examples, is neither specifically human, nor specifically linguistic phenomenon.

My central idea of language acquisition (most probably, not new) is: **the new word never introduces itself alone.**

When a young monkey hears the warning cry of another monkey for the first time, the sign consists of a single "word," but it associates with the subsequent sight of the predator and either a specific collective behavior or just a general commotion. If the predator never appeared after the cry, the effect would fade away.

A word heard by a child for the first time comes either with another word or an object, gesture, action, sensation, appearance, etc. , i.e., as $\{A,B\}$, which leads to:

$$\{A,B\} \Rightarrow AB \text{ , which implies } AB \Rightarrow C :$$

$$\{A,B\} \Rightarrow AB \Rightarrow C; \quad \{A,B,C\} \subset G$$

Two sensations that are close in time or space develop a bond between their representations. For example, the audible word "dog" and a visible particular **dog** can form a link.

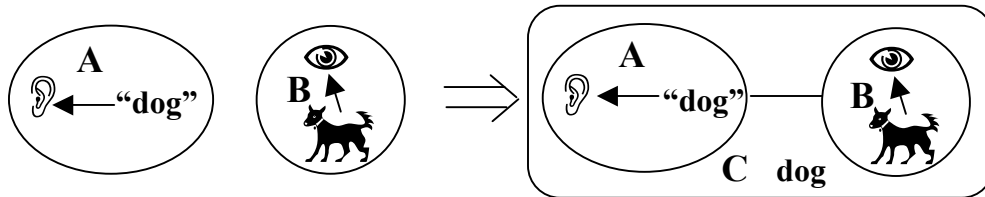


Figure 4. Linking of sound and sight and generation of the idea of dog

A and B can also be two words or just any sounds and their combinations, or an idea and a sensation.

In short, if two sensations belong to the same temporal or spatial set, the bond between their representations “may follow,” which the symbol $\Rightarrow$, similar to the chemical $\rightarrow$, signifies. “May follow” means that this is possible, but how probable, it remains to be investigated. Moreover, the bond can fade away without repetitive stimulus.

Chemistry is very unenthusiastic to the distinction between true and false, but takes a great interest in the questions like “how much? how soon?” even if the target of the question seems false.

I am greatly tempted to extend the chemical analogy even further. All chemical reactions are by their very nature reversible. Only because of some special circumstances, like the irreversible escape of carbon dioxide, baking soda and vinegar cannot be reconstructed from the remaining products of their mixing. In a closed steel tube the equilibrium would be reached.

The correct symbol for chemical reaction is $\rightleftharpoons$, what is usually meant by the single arrow. If we modify our $\Rightarrow$ into $\Leftrightarrow$ (chemical $\leftrightarrow$ means a very different thing than $\rightleftharpoons$), we will suddenly find ourselves facing the beautiful idea that if $AB \Leftrightarrow C$, then whether we somehow get in the focus of attention a **single** A, B or C, all three generators, A, B, and C will float there. It is only because of the limited capacity and speed of our mind that any word does not bring into memory at least one tenth of the entire *Webster's II New Riverside University Dictionary*. ***If words were atoms***, this is what would happen in an infinite time.

Whether we should embrace the idea or not, I would spare it for a separate discussion elsewhere. It is related not to the subject of the poverty of stimulus but to the more general subject of deep analogies between all **natural** discrete complex dynamic systems and to the naïve but deep questions like what is the difference between the dog and the word “dog” and why there is no tangible thing called “animal” in the world.

If a word or sound is not tied to another word or sensation or something else, it is meaningless. All theories of meaning agree on it. Only some words are signs of external reality, but all of the atoms of language are meaningful, as a monolingual dictionary testifies.

7. Acquisition of generators

The visible delimiter, i.e., the space between words, is absent from Chinese, Thai, and ancient Greek texts, not to mention speech. Japanese gives some good cues. It is not seen and mostly not heard by children. Morphemes are embedded into words, too. If the child, ignorant of any theory, identifies verbal generators in the input and uses them, there must be a simple procedure to identify sound bites and their sequences as generators.

The identification of generators is the purpose of pattern analysis. How do we know that a sign (word, morpheme, or phoneme) is a generator? The definition of an atom based on indivisibility is a negative one. There is no way to test the indivisibility *a priori*. Lo and behold, the atoms became indeed divisible. For a dog, *goodboy* is probably atomic. On the contrary, divisibility of speech can be easily established before the entire language has been acquired.

Let us try the following simple rule based on divisibility:

The word or morpheme is a generator if it enters at least two different configurations. This is how the rule looks in our quasi-chemical notation, defenseless against any mathematical criticism:

$$\{XB, XC\} \Rightarrow X \in \mathbf{G}$$

Or: if $\{XB, XC\}$, then, probably, $X \in \mathbf{G}$.

In other words, if at least two generators from a generator space **G** can form bonds with **X**, then **X** is a generator and it belongs to **G**. To put it even simpler, generator is what can bond with other generators but not what cannot be split into generators.

By the same token, if a configuration can bond with other configurations or generators, it is also a generator. This is especially obvious for linear sequences. In writing, the hierarchy of generators is usually portrayed by using brackets of various types. Naturally, formal linguistics uses tree diagrams.

The ultimate simplicity of local rules like the one just described, hypothetically, requires simple innate physiological mechanisms common for all species with nervous system. It does not require learning.

8. Acquisition of bond space

The sophisticated educated language is acquired by different means involving analysis, sometimes slow, of complex sentences and rhetorical devices as well as contact with complex subjects and situations. To learn chemistry, for example, means to learn what you can say about it that will be grammatically, contextually, and factually acceptable, although not necessarily true. I believe that it is crucial for understanding language acquisition to remember that even a complex literary, philosophical, or scientific text could be told in a simplified childish syntax by cutting the sentence into simple segments.

Here is a single sentence from *The Portrait of a Lady* by Henry James:

The large, low rooms, with brown ceilings and dusky corners, the deep embrasures and curious casements, the quiet light on dark, polished panels, the deep greenness outside,

that seemed always peeping in, the sense of well-ordered privacy in the center of a "property"--a place where sounds were felicitously accidental, where the tread was muffled by the earth itself and in the thick mild air all friction dropped out of contact and all shrillness out of talk--these things were much to the taste of our young lady, whose taste played a considerable part in her emotions.

In the beginning, the conversion would go smoothly:

There were rooms. There was a lady. The embrasures too. The light too. The lady was young. The rooms were large. The rooms were low. The ceilings were brown. The corners were dusky. ... The lady liked the rooms. ...

But we would soon run into problems with *these things were much to the taste of our young lady*, which still can be dealt with, but *sounds were felicitously accidental*, and *whose taste played a considerable part in her emotions* are absolutely beyond a child's experience. They are not observable by anybody but the author, in accordance with his esthetic position. To say and understand something like the above sentence requires not only a significant life experience but also an experience in reading literature. Moreover, it requires time to compose and optimize it. The average pre-school child naturally acquires language as a tool to study the higher floors of the edifice of literature at school where the artificial language of the civilization dominates.

I believe that **natural** language acquisition ends with the ability to say who does what in connection to what or whom and in what fashion. The rest, starting with mastering compound sentences, is acquired by learning, analysis, synthesis, and conscious mimicking. It was my personal impression that the Russians with up to seven years of school, especially, in the countryside, hardly ever used compound sentences with more than one clause, which was not to the detriment of content.

Many technicalities of general PT become highly simplified for linear configurations, even more so if we speak only about acquiring a language sufficient for a child to maintain balance with the limited social environment.

The generator of utterance has only left and right bonds. We can assume that they have bond value spaces B_L and B_R on each side. All β are various, possibly, nested tags (*modalities*, along Ulf Grenander [13]) of the generator that signify its multiple categorization: dog is noun, animal, direct or indirect object, etc. on the left, subject, noun, animal on the right, etc. Its grammatical tags can be expressed as morphemes or even by capitalization, as in German, but I am interested how the bond space can be acquired in childhood and not analytically.

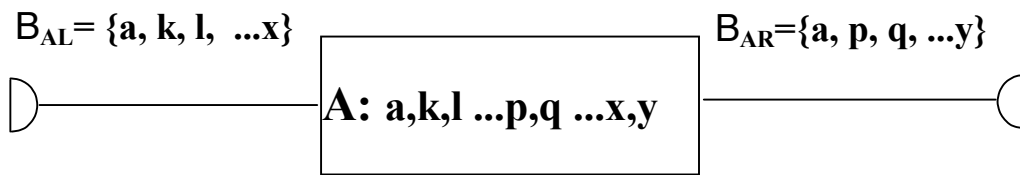


Figure 5. Language generator A

In **Figure 5**, generator A has some bond values twice on both sides, which for example can happen with adjectives or listed nouns. The union of the left and right sets is a complete list of all bond values, which may be enough for languages with loose word order.

For the left-to-right doublet **AB**, bond relation $\rho = \text{TRUE}$ if

$$\beta_{AR} \in B_{BL}, \text{ and } \beta_{BL} \in B_{AR},$$

i.e., if the two generators have the same bond values at the bonds in contact (**Figure 6**).

Thus, “Dog bites man” and “Man bites dog” are equally grammatical. What contradicts the factual content of the sentence, however, decreases the **stability** of the wrong version. This is why some politicians love meaningless clichés.

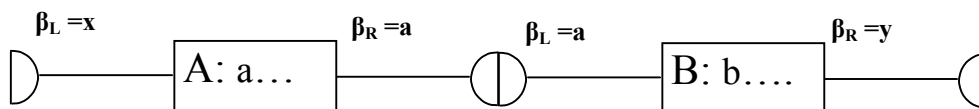


Figure 6. Regular doublet

It all looks much simple for a chemist who would just say that **A** and **B** form a donor-acceptor couple. Even a linguist could not find anything new in the statement that there are grammatical and ungrammatical adjacencies between morphemes, words, and phrases, which is a fair way to put it. I only paraphrase common linguistic knowledge, although I suspect that for any common knowledge in non-experimental linguistics there are two conflicting views. What I claim as new (what can be new after Lucretius, anyway?) is that the rules of grammar, whether universal or specific, extant or extinct, do not need to be stored anywhere in the mind as a book on a shelf. They could be contained—and this is a hypothesis in need of a test—in the properties of generators, similarly to the way molecules assemble not by principles and parameters but by the properties of the atoms.

The knowledge of regular grammar, from the point of view of a chemist, is distributed among generators, up to a certain level of language evolution. Philosophers, scientists, and writers have inflated the language to such excess that poor children have to study their native tongue for many years at school, picking up irregularities from the peers.

9. Acquisition of bond values

The next important question on the agenda of language acquisition is generator classification. How are the bond values, which are signs for classes, acquired? Here is an extremely simple and local rule:

$$\{AB, AC\} \Rightarrow \{B,C\} \subset G' \subset G$$

It means that if two generators **B,C** combine with the third **A**, they have the same bond value, acceptable by **A**. In other words, **B** and **C** belong to the same subset

G' of G . It means that the partition of generator space into classes is done by the generators they can share. “Tell me who your friends are and I will tell who you are” is invertible: “Tell me who you are and I will tell who they are.” The newly formed class can expand in the same way or disappear if the juxtaposition of AB and AC was accidental. This is how language can be acquired in a quite mechanical way by children who would give very little thought to anything but fun and who will rise to higher levels of language only when they develop abstract thinking that takes time and is not automatic.

Of course, this is only a hypothesis. Probably there are some supporting or contradicting works in linguistics literature.

Remarkably, every act of juxtaposition of two doublets with a shared element works both ways: (1) identifying a new generator and (2) identifying a class:

$$\{\textcolor{red}{A}-B, \textcolor{red}{A}-C\} \Rightarrow A \in G$$

$$\{A-\textcolor{red}{B}, A-\textcolor{red}{C}\} \Rightarrow \{B,C\} \subset G' \subset G$$

Next, $\{B,C\} \Rightarrow D$! The class acquires its sign.

The effect depends on whether A or the bond with A is **new**. The notion of **novelty**, absent from mathematics and physics, but not from chemistry, where a molecular structure does not exist unless *a posteriori* and *de facto*, is of cardinal importance for the formalization of evolution, which is exemplified by language acquisition. What the original UG concept seems to say is that there is nothing **new** in language acquisition but just selection from a timeless menu.

A stone falls from the Tower of Pisa? No big deal, all possible trajectories and acceleration existed before the fall. The stone has chosen its trajectory, which is not so strange an idea for classical optics and quantum physics.

Nevertheless, formal linguistics, driven by Chomsky himself, has been undergoing such an involution toward simplification (X-bar) and quantification (optimality), that sooner rather than later it is going to fuse even with the principles of PT,

like Monsieur Jourdain, without realizing it. I draw attention to PT not because I do not believe that linguistics cannot find its own way to consensus, but because it illuminates the place of linguistics among other natural sciences, where my native chemistry dwells nearby.

I try to show in **Figure 7** how the X-bar concept can be converted into its PT form by excluding **imaginary** XP and X'. The resulting generator has arity 3 (number of bonds) and is not good for building strings. This is why formal linguistics in all its forms has to bend over backwards to find **imaginary** movements and linearize the typically non-linear trees.

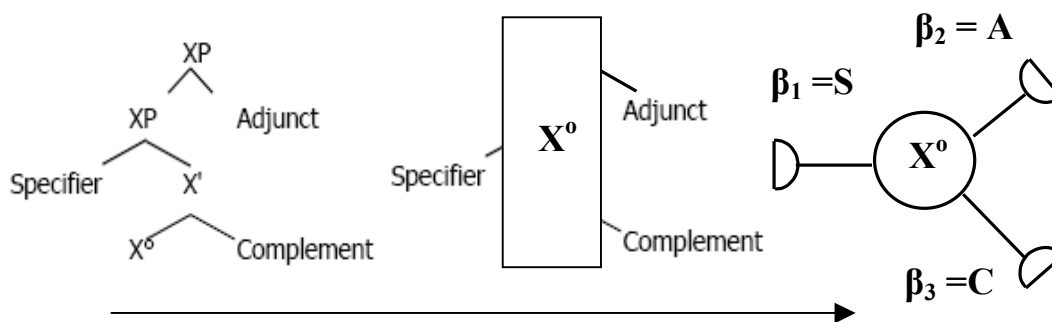


Figure 7 . From X-bar (left) to generator (right). A: Adjunct, etc.

If the notation $\{A,B\}$, as I said, means that A and B are not just elements of a set but are **close** to each other in some realistic sense, the transformation sign $\Rightarrow$ in $\{AB, AC\} \Rightarrow \{B,C\}$ needs clarification. If the elements are on the left of $\Rightarrow$, they are close in perceived reality. We say that they are in the same topological neighborhood in time and/or space and form a distinct cluster. There must be some physical or physiological reason why we assemble them in the brackets. Coming back to the analogy with the singles bar—a refreshing step away from X-bar—the brackets on the left of $\Rightarrow$ represent the singles bar, say, at 8 PM and on the right we see the same bar at 10 PM.

The closeness does not mean the Euclidean distance. A good example is a circle of friends who may be separated by the entire continent or just a street but call each other over the telephone with the same minimal effort. A better term is the channel of communication, for which the maximum distance between humans we know is from the Earth to the Moon. At the other end of the human scale are communicating neurons. The physical counterpart of communication is interaction and the chemical one is collision.

Human intellectual functions shuttle between the mind and the real world as—you've guessed it right—the bees shuttle between the flowers and the beehive.

Expressions like $\{A,B\}$ and $AB \Rightarrow C$ suggest another obvious idea: the concept of a strong bond is an expansion of the concept of the set. In real world and in the real mind, elements are placed into the same set for a reason. They **might** form a bond if they stayed in the set long enough, and fuse if when they stayed even longer. We can say that $\{A,B\}$ and C are at the two ends of a continuous scale with AB somewhere in the middle.

10. Locality

Locality in current context means that in the process of acquisition and identification we look only within a 1-neighborhood (immediate topological neighborhood, see **Figure 8**) of the generators and not any farther than that. We do not need to consult either a grammar or an algorithm. No long term memory is needed to keep intermediate data because they all are on hand.

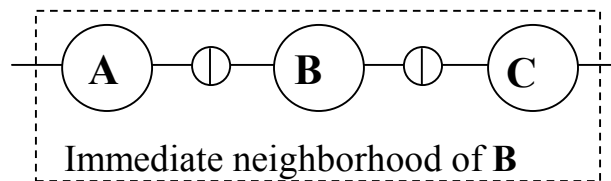


Figure 8 . The substrate of local operations

The target for both identification and classification is the same: two generators in the neighborhood of the third one. The identification of the generator (if generator combines with two others... etc.) is simply seen from the other side: if two generators form bonds with the same third one, they belong to a subset (class) of $\mathbf{G}$. Therefore, the class is defined by the affinity (or aversion) of all its elements to a common generator.

As I believe, what the child gradually acquires is not any grammar as the list of rules, like the basic word order SVO, but the hierarchical partition of sounds into morphemes, words, word groups, phrases, and stylistic devices that constitute the generator space in which generators have specific bond structures, so that SVO order in English comes out automatically as soon as the abstract generators S, V, and O are formed. Of course, the pre-school child has no idea about syntactic categories. When the speech is generated, the content and form are reconciled in the process of linearization toward the minimization of stress [3].

11. Some examples

This is an imaginary way how the high level generators and patterns can be acquired by a child-robot:

$$\{\text{eat—apple}, \text{eat—carrot}\} \Rightarrow \{\text{apple, carrot}\} \subset G_1 \subset \mathbf{G}.$$

$$\{\text{eat—apple, take—apple}\} \Rightarrow \{\text{eat, take}\} \subset G_2 \subset \mathbf{G}$$

$$\text{Pattern: } G_2—G_1$$

$$\{\text{Mary—eat}, \text{Mary—take}\} \Rightarrow \text{Mary}—G_2$$

$$\text{Pattern: } \text{Mary}—G_2—G_1$$

$$\{\text{Mommy—eat, Mommy—take}\} \Rightarrow \text{Mommy}—G_2$$

$$\{\text{Mary}—G_2, \text{Mommy}—G_2\} \Rightarrow G_3 = (\text{Mary, Mommy}) \subset G_3 \subset \mathbf{G}$$

$$\text{Pattern: } G_3—G_2—G_1$$

Much later the child learns at school that G_3 , G_2 , and G_1 are terms of syntax and discovers that he or she had been guided by the invisible hand of the Grammar.

Here is another imaginary example, inspired by observations on acquisition of German noun gender by native children [10A] : acquisition of the German case-gender-number nominal marking system.

Vocabulary: Hund: dog; Hundchen: puppy dog, Mäd: the word does not exist; Mädchen: girl; -chen: suffix of diminutive form, marker of Neutral Gender.

$$\{\text{Hund, Hundchen}\} \Rightarrow \text{Hund-} \in G$$

$$\{\text{Das_Hundchen, Das_Mädchen}\} \Rightarrow \text{-chen} \in G$$

$$\{\text{Ein_Hund-chen, Das Hund-chen}\} \Rightarrow \text{-Hund-} \in G ; \text{ similarly,}$$

$$\{\text{Hundchen, Mädchen}\} \Rightarrow (-\text{Hund-}, -\text{Mäd-}) \subset G_{\text{-chen}}$$

$$\{\text{Das A-chen, Das B-chen}\} \Rightarrow \text{Das—}G_{\text{-chen}} ; (A, B) \subset G$$

Next, consider the basic word order of subject, direct object, indirect object, and verb. For English Imperative, the triplet in **Figure 9** serves as a template.

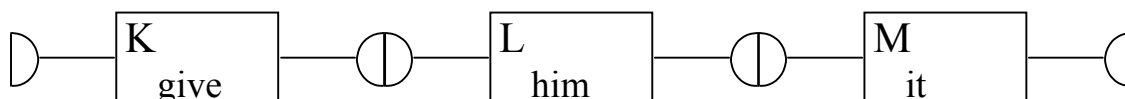


Figure 9. Pattern template

Here K and M are in the immediate neighborhood of L . K , M , and L represent whole classes of generators.

The triplets constitute already a transition phase from Nean, the language of doublets, to the advanced grammaticalized language, in which the alternatives of word order start branching, leading to the abundant, but not unlimited, variety of languages.

The probabilistic approach to syntax in [18] comes very close to the idea of Nean as the language with doublet or triplet syntax resulting from haplology [3]. Moreover, this work

suggests another idea: the sentence is generated from overlapping short fragments. I would call it **tiling**.

The advanced natural evolution of syntax when there was still no Henry James and William Faulkner in sight is a separate problem. As a mental experiment, we can try to guess why, under the pressure of linearization, in polysynthetic languages like Mohawk the **L—M** doublet develops into a verb prefix, in highly inflected Slavic languages, like Russian, the same doublet takes form of case endings, and in English it mostly evaporates, leaving only the ephemeral word order:

Jack he-her-like Mary (Mohawk)

Jack like-he Mary-her (Russian)

Jack like-he Mary (English)

All three syntactic constructs contain all necessary information to avoid ambiguity.

With an indirect object, “Give Alex the toy” would look like “You-him-it-give toy Alex” in a strongly polysynthetic language and “Give-you toy-it Alex-to” in a highly inflected language. Nevertheless, I could not find in my limited corpus of Mohawk, collected from the Web, anything like “you-him-it,” which would generate up to a thousand of different verb prefixes.

Sak wa'-ku-hsvn-u-'.

Sak fact-1sS/2sO-name-give-punc (linguistic glosses)

Sak indeed-I-you-name-give-this_moment

‘I (hereby) give you the name Sak.’

Here (the example is from [19]) *punc* (' , which is a sound) means that the action is one-time and *fact* (wa') means the factual mood. Morpheme *ku* means “I (subject) [do it to] you (object)” and “Sak” is not marked by any morpheme. The distinction between direct and indirect object, sharpened by word order or preposition in English, is blurred here, but the content is absolutely clear. This confirms to me that the distinction between

syntactic categories like direct and indirect object is rather artificial. In the configurations of thought [3] only bond couples are real. Moreover, I think, together with some linguists, that the grammatical categories like verb and noun are not without borderline fuzziness, especially in the non-Indo-European languages, but the Indo-European origin of grammar strongly influences our thinking.

In the above Mohawk example [19], “name” (*hvsn* ; *v* is a nasal vowel) immediately precedes “give” (*u* , another nasal vowel) creating the compound verb “namegive” (*hsvnu*), in a manner common also to German. But the Russian language does not mind scattering the three endings all over the phrase. The diluted medicine is less bitter, but the body of the Russian sentence can grow bloated.

We can speculate about why the extraordinary redundancy of Russian and Polish (shared, it seems, by Swahili) has survived thousand years, satellites, and perestroika and why the inflective redundancy of Old English was so fragile. The tribal languages, it seems, aimed at rendering the nonlinear thought in the most straightforward way, making clear who did what to whom, without requiring any guessing. This holistic property of tribal languages—and they can have an astonishing complexity—was, probably, perpetuated by a limited number of situations meaningful for the tribal society. We can find the most generic ones in folk tales. This became an atavism after entering the modern era with literacy as the most powerful stabilizing factor.

Unlike the English nation, the Russians did not know intense ethnic mixing. The Mongol invasion and 240 years of their domination added some words to the vocabulary but the two people did not actually mix. The Mongols either lived a separate life or accepted the Russian one.

With PT approach we might find that the excruciatingly thorny problem of the evolution of language is not hopeless. Like in chemistry, we may find out what is “more true” and more expedient **at given conditions**, which are accessible to archeology. I can imagine a research—no doubt, very difficult—of relation between the way of life and the structure and vocabulary of tribal languages, but I am not aware of it. To separate language from conditions of life and culture would be equivalent to ignoring conditions

of chemical reaction, i.e., temperature, pressure, agitation, catalysts, acidity, irradiation, etc., by a chemist. Whether language defines culture, I have no opinion. But if culture defines language the observable result will be the same. This is yet another case of circular logic, which can be resolved only in one way: the less stressed complex of culture and language survives.

Linguists cannot forget the debates over Benjamin Worf's denial of category of time in Hopi. It turned out that he was partly right. Some strange things with tenses happen also in Mohawk [19]. There is a sophisticated system of Future Tenses in Maya. In my view it is only natural that the perception of time in a tribal pre-industrial society could be very different from ours, shaped by timetable, heat engine, clock, and fertility of imagination. I feel comfortable with the idea of the past as what will **always** be in the future, like the death of a relative, and the idea of the future that is a pure **possibility, intent** (I will eat), or just **present**—all without any guarantee of realization. The present can be expressed not only by *I'm going to eat*, *je vais manger*, and *eszni fogok* (Hungarian), but also by simple Present used in Russian and Hungarian as Future with an adverbial modifier of time. The Bulgarian Future Perfect, with two auxiliary verbs and an unusual pattern of change, is truly remarkable from this viewpoint, as the entire florid Bulgarian verb system is. On the other hand, the ghostly Future in Japanese is another convincing illustration of the idea that, come to think about it, there **is** only Past and non-Past in the naïve physics of the world. We can talk about future, but it certainly does not exist. Every philosopher starts with inventing his (this is a truly manly occupation) own language.

12. Language and homeostasis

From the PT point of view, the language generation amounts to the problem of **pattern synthesis**, which is the production of regular configurations of the same pattern.

Our next and last step is pattern synthesis during language acquisition. How to ensure that the acquired language takes a grammaticalized shape and not just any shape,

but that of the surrounding language? How are patterns selected? In general, the generator space does not guarantee a unique way of self-assembly of generators into configuration neither in chemistry, as isomers demonstrate, nor in linguistics, as the languages of loose word order and even the two forms of indirect object illustrate.

Unfortunately, as I believe, chemistry can tell us at this point very little, if anything at all. This pessimism is not shared by the whole school of evolutionary linguistics that simulate language evolution within the framework of competition and selection, based on groundbreaking models of Manfred Eigen and his group. This direction is represented in linguistics by Martin Novak, whose background is in mathematics, biology, and evolutionary dynamics [20]. Instead of criticizing these highly valuable and insightful models, under the spell of which I have been for over 20 years, I will make a constructive (I am sure, not new) suggestion of an ultimate simplicity.

The language acquired by a child differs very little from the ambient one because of social homeostasis. Speaking a non-standard and peer-challenging language and suffer mutual misunderstanding as consequence would create a stress, which most human and animals, except some born leaders and troublemakers, would avoid by any available means. In psychology it is known as theory of balance.

The patterns of speech based on the acquired generator space will be selected not so much by individual selective advantages as by the stability of the whole. Here I have little to say but to refer to [3] and [4].

I cannot resist a temptation, however, to generalize this principle over biological evolution, the area which, in spite of Darwin and molecular biology, is as far from consensus as linguistics. Evolution of species is not (I say it arrogantly, without any “not only”) the survival of the fittest, because the fittest is always the one who survives, but the homeostasis of the biosphere subject to external (for example, climatic), internal (for example, cyclic or catastrophic non-linear fluctuations), or just random perturbations.

A non-equilibrium dissipative system, to which all life (*biosphere*) and its manifestations (*noosphere*) belong, searches and finds a way to end the stress of the perturbation. I believe this idea follows from the ideas of Ilya Prigogine [21] and William Ross Ashby. [22] The concept of punctuated equilibrium [23] is the closest to

it. One of the cardinal insights of this entire approach is that the disturbed complex dissipative system returns not to the previous state, which is hard to find among enormous number of possible states and pathways, but to a **new** and more stable one. This is what makes dissipative systems so different from common chemical systems which automatically find the point of equilibrium.

Homeostasis is a highly natural way of thinking for a chemist even though very few chemists deal with dissipative systems.

What do you think happens when you disturb the universe by mixing baking soda and vinegar? It dissipates carbon dioxide and comes not to the previous state but to a new one, from which there is no way back to the previous one. Moreover, nothing else can happen there on its own.

You can heat up and cool down a flask with chemicals millions of times with the same result, but the Sun warmed up the Earth and left it to cool down millions of times until life stepped out because the Earth was an open system.

The live dissipative system can change many times without the interference of the chemist or, for that matter, anybody else, while the supply of solar energy lasts.

To illustrate this idea, the discovery of the mineral fuel and heat engine was a great disturbance of the previous civilization. It first occurred locally, between Manchester and Birmingham. Today it brings global civilization in turmoil. To recuperate, we are burning the mineral fuel in increasing amounts until the homeostasis will be, hopefully or woefully, restored in a new civilization, which may not welcome humans as we know them at all.

Conclusion

Why in the world are we speaking about thermodynamics? Isn't chemistry far enough from linguistics? And isn't it obvious that I cannot **prove** a word. No, I can't. I do not consider myself an amateur linguist. I am only a chemist. But I would like to plant a seed of something other than just a doubt in Plato's idea.

Why the verb in Mohawk, Inuit, and other polysynthetic languages is so loaded with short morphemes indicating moods and aspects, not to mention major syntactic functions, why the verb in Japanese is practically naked and so is the attributive adjective in the noun- and verb-overdressed Hungarian, why French has a fair number of tenses but the otherwise much sparser English is not too far behind, why the Titianesque Russian has no article and the noun-frugal Bulgarian slaps the article onto the noun from behind, why English lacks diminutive, derogative, and affectionate suffixes, present in Italian, essential in Russian, and some showing up even in the stern German, and why Yiddish has no simple Past Tense—such questions could be answered if a function similar to energy of a molecule or some other measure of **stability** could be found for any segment of speech—which is just a thought, crudely squashed (but don't **mince** your words!) and drawn through a narrow hole regardless of the word segmentation.

Of course, we speak as our forefathers did, but there was some reason why they had departed from their non-speaking forefathers. If there are some laws of nature, they apply to both our forefathers and little children.



Figure 10. Bees carry pollen, words carry grammar

I believe linguistics could move closer to the status of natural and consensus-based science if one fine morning it discovered in the alien chemistry its own reflection in a gritty, wavy, cracked, but still a mirror. I hope chemists, on their part, could someday realize that they can give something else to the world except pollution, side effects, and genetic danger: the flowers of **new** universal ideas.

As for the language acquisition, see **Figure 10**.

NOTE (February, 2007) . In my view, nothing supports the “bee” mechanism of language acquisition as much as the data about bilingual children. They do not mix languages, although nothing seems to prevent them from mixing up at least the nouns. In the “bee” ideogrammatic language, the two bee species feed on two different species of flowers.

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APPENDIX

THE CHEMISTRY OF THE THREE LITTLE PIGS

As a **preliminary** illustration of some ideas expressed in this paper, I will explore a fragment of a text as a substrate for elementary local operations of generator and bond space acquisition. It is by no means a description of the mechanism itself because the real perception and processing of the text is diachronic, while my examination is going to be synchronic. The text here comes into view not bit by bit, as it should, but as a chunk.

A simulation of language acquisition, as I believe, cannot be done with any single compact segment of perceived speech as input. A minimal requirement of a realistic simulation is a long series of language stimuli, coming in packages, like the Internet content, over an extended time, and against a background of realistic interactive content. This is a difficult task, remotely comparable with designing a game like the Sims, <http://thesims.ea.com/us/>.

There are scores of works on child language acquisition, and corpuses are available, but direct observations of children are intrusive and difficult to realize on a large and comprehensive scale, as even the works on chimp language testify.

We have numerous theories of the origin of the universe, life, and language because we cannot observe the origins. Nevertheless, most scientific theories work near perfectly every day. **The bulk** of linguistic theories can be tested by building a talking, writing, and translating machine that develops its abilities in human environment, from scratch, and without any algorithm. This is still easier than to create the universe.

The target text is a compact modified fragment from the tale of *The Three Little Pigs*.

Source: Jacobs, Joseph. "The Story of the Three Little Pigs." *English Fairy Tales*. London: David Nutt, 1890. <http://www.surlalunefairytales.com/index.html>

The target text P is a character array of 130 words, given here in the form of MATLAB input:

```
P = char ('_', 'there', 'was', 'an', 'old', 'sow', 'with', 'three', 'little', 'pigs', 'and',
'as', 'she', 'had', 'not', 'enough', 'to', 'keep', 'them', 'she', 'sent', 'them', 'out', 'to',
'seek', 'their', 'fortune', '_', 'the', 'first', 'that', 'went', 'off', 'met', 'a', 'man', 'with', 'a',
'bundle', 'of', 'straw', 'and', 'said', 'to', 'him', '_', 'please', 'man', 'give', 'me', 'that',
'straw', 'to', 'build', 'a', 'house', '_', 'which', 'the', 'man', 'did', 'and', 'the', 'little',
'pig', 'built', 'a', 'house', '_', 'presently', 'came', 'along', 'a', 'wolf', 'and', 'knocked',
'at', 'the', 'door', 'and', 'said', '_', 'little', 'pig', 'let', 'me', 'come', 'in', '_', 'the', 'pig',
'answered', '_', 'no', '_', 'the', 'wolf', 'then', 'answered', 'to', 'that', '_', 'then', 'I', 'I',
'puff', 'and', 'I', 'I', 'blow', 'your', 'house', 'in', '_', 'so', 'he', 'puffed', 'and', 'he',
'blew', 'his', 'house', 'in', 'and', 'ate', 'up', 'the', 'little', 'pig', '_')
```

We apply to the target the following transformations written as “chemical” reactions, in which X is a variable. By “chemical” I mean, actually, “pattern-theoretical,” but I cannot use the latter term because the ideas are not explicitly formulated in PT. I infer them perhaps incorrectly. **Equilibrium** is a “chemical” counterpart of **equivalence** and **association** in cognitive sciences. It means, half-seriously, that if one thinks about three little pigs (A), the wolf (B) promptly comes to mind because the entire story (C) is remembered. The story is in equilibrium with all its components, which is pretty close to the chemical idea of equilibrium. I cannot invade the heartland of cognitive sciences, but from a distance I would repeat again the parallel between the chemical flask and the mind.

$$\{A,B\} \Leftrightarrow \{AB\} \quad \text{bonding equilibrium} \quad (1)$$

$$\{AX,BX\} \Rightarrow X \in G, \quad \text{generator identification} \quad (2)$$

$$\{A,B\} \Rightarrow C \quad \text{generator categorization} \quad (3)$$

$$\{A,B\} \Leftrightarrow C \quad \text{representation equilibrium} \quad (4)$$

$$\{AX,BX\} \Leftrightarrow CX \quad \text{bonding categorization and} \\ \text{its representation equilibrium} \quad (4)$$

Using a simple program, a **vocabulary** of 71 words, including space (_), was extracted from P and the words were analyzed for their left and right neighbors in P. The results are in the Table:

Table : Vocabulary and neighborhoods of *The Three Little Pigs*

Left neighbor	No.	Word	Right neighbor
fortune him house house said in answered no that in	1	_	the please which presently little the no the then so
_	2	there	was
there	3	was	an
was	4	an	old
an	5	old	sow
old	6	sow	with
sow man	7	with	three a
with	8	three	little
three the _ the	9	little	pigs pig pig pig
little	10	pigs	and
pigs straw did wolf door puff puffed in	11	and	as said the knocked said I he ate
and	12	as	she
as them	13	she	had sent
she	14	had	not
had	15	not	enough
not	16	enough	to
enough out said straw answered	17	to	keep seek him build that
to	18	keep	them
keep sent	19	them	she out
she	20	sent	them
them	21	out	to
to	22	seek	their
seek	23	their	fortune
their	24	fortune	_
_ which and at _ _ up	25	the	first man little door pig wolf little
the	26	first	that
first me to	27	that	went straw _
that	28	went	off

went	29	off	met
off	30	met	a
met with build built along	31	a	man bundle house house wolf
a please the	32	man	with give did
a	33	bundle	of
bundle	34	of	straw
of that	35	straw	and to
and and	36	said	to _
to	37	him	_
_	38	please	man
man	39	give	me
give let	40	me	that come
to	41	build	a
a a your his	42	house	_ _ in in
_	43	which	the
man	44	did	and
little little the little	45	pig	built let answered _
pig	46	built	a
_	47	presently	came
presently	48	came	along
came	49	along	a
a the	50	wolf	and then
and	51	knocked	at
knocked	52	at	the
the	53	door	and
pig	54	let	me
me	55	come	in
come house house	56	in	_ _ and
pig then	57	answere d	_ to
_	58	no	_
wolf _	59	then	answered I
then and	60	I	ll ll
I I	61	ll	puff blow
ll	62	puff	and
ll	63	blow	your
blow	64	your	house
_	65	so	he
so and	66	he	puffed blew
he	67	puffed	and
he	68	blew	his
blew	69	his	house
and	70	ate	up
ate	71	up	the

The following is a kind of chemical analysis of the table.

We encounter some doublets and triplets of high occurrence in everyday speech, for example:

2	there	was
---	-------	-----

15	not	enough
----	-----	--------

54	let	me
----	-----	----

39	give	me
----	------	----

she	14	had	not
-----	----	-----	-----

she	20	sent	them
-----	----	------	------

In chemical language, if used frequently, the doublets and triplets can crystallize and form composite generators, provided the abstract **temperature**, which is the level of chaos, is low enough. In **P**, however, the statistics is meaningless because of the small size.

The following is a series of examples of what can “chemically” happen with **P** as a substrate.

1.

25	the	first	man	little	door	pig	wolf	little
----	-----	-------	-----	--------	------	-----	------	--------

THE creates the tentative class of all words right of **THE**. The classification may diachronically survive or fall apart. We need a name for the class, and **THE-X** is a natural one.

Class THE-X: X= {first, man, little, door, pig, wolf}

We know that **THE-X** includes both nouns and adjectives, but the child-robot does not know grammar.

2. Similarly:

31	a	man bundle house house wolf
----	---	-----------------------------

Class A-X: X= {man, bundle, house, wolf }

These two classes can be expressed in terms of the vocabulary entries.

Since the class is in equilibrium with its entries, MAN is in equilibrium with its class (possibly, one of many).

Class X-MAN : X = {a, the} and, therefore, **X= A-X , THE-X.**

Confirmed by many occurrences, this classification will, most probably, survive.

But then A and THE form also a class, for which we are out of the names other than cumbersome A_THE. Of course, we now know the current name of the class: **article**, by the way, absent in many inflected languages.

45	pig	built let answered _
----	-----	----------------------

3. Similarly:

an	5	old	sow
----	---	-----	-----

and

three	the _	the	9	little	pigs pig pig pig
-------	-------	-----	---	--------	------------------

would allow for inferring the distinction between nouns and adjectives, not quite reliable yet:

X-Adjective-Y: X=Article, Y= Noun

There is not enough data to form the class of nouns, however, but we can easily imagine that with enough verbs.

The above examples could make us feel what a little child feels when acquiring the knowledge of the world: what we know and what seems elementary and obvious must to be retrieved from the formless mass like the statue of David from the block of marble. Unlike the sculptor, who cannot make a big mistake with the stone, the child's mind works like a scientist—or living nature—creating, testing, and rejecting hypotheses.

The overall picture of language acquisition—and, therefore, of language genesis—becomes the field for competition of patterns, which are counterparts of biological species, and not individual sentences. When the starting pattern is as simple as doublet or triplet, further mutations can generate the largest variety of grammars, which explains why the languages are on the surface so different. The mutations of developed grammars are, of course, less radical.

The German separable verb prefixes seem to contradict the principle of locality, but if we start with simple situations and short phrases, German is no more strange than Japanese with its verb invariably at the end.

We can hope to reconstruct the process of linguistic genesis for two reasons: (1) we can understand the world of the first speakers where somebody does something to somebody or something, (2) we have only two choices for adding a new generator (morpheme): left and right of the old one.

The short fragment illustrates only the main principle: **if the words were atoms, there would be a chemistry of words**. Linguists can easily see some parallels with the widely used connectionist models, methods of statistical inference, Bayesian categorization, and the so-called memoryless learning algorithms, when the next entry either confirms or contradicts the already formed rule, but the data are not stored. Language acquisition fits into the fast growing area of unsupervised learning. It may turn out that there is much more consensus in linguistics than it appears, but the various areas do not have a *lingua franca*. The cobbler walks barefoot.

The comparison of “chemical linguistics” with current approaches is a separate topic to be discussed elsewhere. I will refer here only to the close in spirit and crisp in ideas work of Sylvain Neuvel and Sean A. Fulop, *Unsupervised Learning of Morphology Without Morphemes*, <http://arxiv.org/abs/cs.CL/0205072>, where the sign $\leftrightarrow$ in

$$|X|_{\alpha} \leftrightarrow |X'|_{\beta}$$

means “bi-directional implementation,” which is very close to what I want to express with my sign $\Leftrightarrow$ and what is the closest parallel to chemical equilibrium. The algorithm for morphological analysis, i.e., identification of morphological generators, as I would say, based on this principle, works on a POS-tagged lexicon. POS here means not *poverty of stimulus* but *part of speech*. What I expect from the three little pigs, however, is the POS-tagging.

Being strictly local, the “chemical” or “unsupervised” mechanisms seem to lead toward the distributed intelligence, working at many levels, from morphemes to phrases, creating, literally, a distributed grammar. It may open way to new types of hardware based neither on linear nor on parallel but on commutation processors [4] that imitate the chemical reaction vessel. In such hardware, an artificial molecular chaos must be maintained. The World Wide Web is a prototype of such a machine. The WWW is a big distributed intelligence, but the remaining problem is how to turn human minds into extremely simple automata with the properties of neurons without the properties of agents.

The examples in **Appendix** illustrate nothing but a vague guess. Its further development, as well as comparison with other linguistic models of acquisition should be better left to those off-beat bees who might become attracted by the chemical smell of strange flowers. The entire direction of Darwinian linguistics, started by Manfred Eigen and continued by Martin Novak may then look like a blooming meadow. But as a chemist, I cannot resist my addiction to chemical smells.

THE CHEMISTRY OF SEMANTICS

Yuri Tarnopolsky

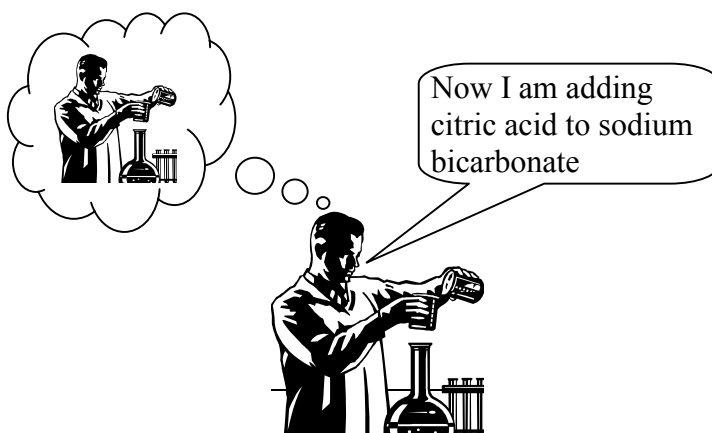
2005

ABSTRACT

This preliminary e-paper continues the examination of language as a quasi-molecular system from the point of view of a chemist who happens to ask, “What if the words were atoms?” The general principles of atomism, locality, simplicity, and transition state are applied to the unobservable structure of thought, regarded as a configuration in Pattern Theory (Ulf Grenander). The non-linear thought interconnects maximum three atomic observables and the coordinate of change in the configuration. The thought is subject to linearization in order to be translated into an utterance. The verb is regarded as the lexical marker of the coordinate of change.

KEYWORDS: semantics, thought, idea, meaning, language acquisition, protolanguage, Navajo, language, pattern theory, chemistry, chemical nomenclature, speech generation, Ulf Grenander, Leonard Talmy.

What if the words were atoms?



THE CHEMISTRY OF SEMANTICS

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2005

1. EXAMPLE

Left side: Horemheb gives drinks to Hathor.

A copy of a picture from the tomb of Horemheb, who became pharaoh around 1321 BC.

Right side: Written representation of the idea of giving in Egyptian, Chinese, English, Swahili, Russian, Navajo, and Hungarian.

I see **the pharaoh**, **the goddess**, and **the drinks**. But where is **the give**? And what about **the to**?



2. INTRODUCTION

It is quite remarkable that the subject of meaning, with which everybody is intimately familiar, is so evasive. The mind is still an open frontier for thought.

The literature on semantics and its various aspects is enormous [1] but not really contentious. It seems that any contributor to it is able to offer his or her own system and notation to represent meaning, without joining an army, however.

As I believe, the lack of a consensus combined with the absence of an intense debate is a good evidence that the subject of a discussion either does not exist or should be looked at from a different angle.

There could be little, if any, debate about the meaning of the absolute majority of particular words (although even the existence of word is debated), but not about **meaning** itself. Does meaning exist? Is it anything else than what we find in any monolingual dictionary? For my part, I am completely satisfied by the article **meaning** in Webster's II:

1. Something signified by a word. 2. Something one wishes to convey, esp. by language. *Etc.*

If I am content with the obviously vague "something," it is because I usually know what **I** myself mean (but see my concluding remarks). The problem arises when we realize that although the dictionary definition is the result of a consensus, no dictionary can tell you what Mr. Smith means right now by saying "I don't like it at all" or Mrs. Johnson wished to convey yesterday by saying "So nice to see you." Are **meaning** and **intent** the same? There are split opinions, too. One can find in the literature a collection of mental variations on the theme of meaning as Baroque as Bach's *Goldberg Variations*.

It is, in short, music which observes neither end nor beginning, music with neither real climax nor real resolution, music which, like Beaudelaires's lovers, "rests lightly on the wings of the unchecked wind." Glenn Gould <http://www.rjgeib.com/music/Top-Ten/gould.html>

I am neither a linguist nor a philosopher. All I want is to launch the problem on the wings of the chemical wind and see whether it flies.

As somebody who did some volume of translation, I can testify that there is no general problem in rendering meaning across the language barrier. All problems of translation, however pervasive, are minor, specific and local. Although there is no way to know what exactly people meant by writing a sentence in Hungarian or Japanese, we can usually have a very good guess and normally know it precisely. Even machine translation can do a good job in most cases. Moreover, machine translation within a very narrow professional context, for example, weather or medicine, where consensus dominates, can

be very successful. The absolute majority of professional languages are tailored to avoid (and rarely to enhance) ambiguity. All I needed in order to translate a piece of technical literature from a foreign language was to understand how the described device or system looked, worked, or behaved. I did not care about what the author thought. To understand meant to say it in my native language, although some moment of a sudden revelation could precede it in hard cases.

I believe that theoretical semantics is an attempt to represent by means of human language what by definition is as little observable as a deity: human **thought**. This apparent paradox dissolves if we separate language from thought and thought from meaning. Language **is** the language of thought. Period. Without language the thought is mute. But what **is** thought? Language is a kind of order. Is thought a kind of disorder? This verbal prestidigitation makes some sense to a chemist.

This e-paper continues the examination of language as a quasi-molecular system from the point of view of a chemist who happens to ask, “What if the words were atoms?” [2]. By analyzing the text of a folk tale as a sequence of short fragments and following a few simple rules we can see how the language acquisition creates a quasi-chemical system in which some sequences (“molecules”) are more probable than others and some are quite improbable. For example, in the system of the *Tale of The Three Little Pigs* [2D] we can generate sentences **Pig built a house** and **Man gave the straw**. Although **Pig gave the straw** and **Man built a house** (as well as other combinations) are not supported by the context, the pattern **Subject Verb Object** is. This all is well known in computational linguistics and all a chemist could add is a different mode of thinking, which I call—defiantly—**simplicity**. It is natural for a chemist to regard anything complex as a structure (molecule) of atomic (i.e., **simple**) objects held together or rearranged by local (i.e., **simple**) interactions.

Although the idea of a computing homunculus is deeply alien to chemistry, the idea of chemistry is not alien to computation [2G]. Neither is the idea of language to chemistry.

The problem, illustrated by the above examples, from pharaoh to pig, is: what happens right before we irreversibly release the utterance into the air and even before we silently formulate it to be released ?

3. CHEMISTRY AND CONFUSION

Chemistry found itself in the state of a teenage confusion right before turning into science about one and a half century ago. It was clear that matter consisted of some unobservable units that could be combined in different quantities. This paradigm, as old as science itself, had been laid out in eloquent verses by Lucretius, the Roman devotee of much less preserved by time Democritus the Greek.

What chemistry accomplished, due to Alexander Butlerov (1828-1886) and Friedrich August Kekule (1829-1896), was to separate the chemical reality, as it is seen—but not understood—through the transparent wall of the flask, from what we cannot see but can understand. It was done by a kind of minimalist program: we have no idea what is going on there, but we are able to deduce which Democritean entities (atoms of chemical elements) are in the substance and which of them are connected.

Starting with Jacobus Van't Hoff (1852-1911), the very first Nobel Laureate in chemistry (1901), chemistry has been eagerly acquiring from physics all the new gadgets invented to see the atomic details directly. Van't Hoff was among the first to look molecules right into the face (and what he saw was a kind of the double image which the drunks are believed to see). Before the modern instrumentation, the fact of the absence or presence of a chemical bond between two atoms could be only deduced logically from the observable behavior of the molecule, for example, by chemically splitting **A—B—C—D** in the middle and identifying the

fragments **A—B** and **C—D**. In the art of connecting the dots the chemists had to have the skills and talents of Sherlock Holmes and Dr. Watson combined.

If thought is represented as atomic entities connected in a certain order, which is what semantics does for living, the way chemistry handled the invisible may be instructive for semantics. In what order? This we can deduce from human behavior, especially, from speech. But, as chemistry discovered at some point around 1950, the real state of molecular affairs in the flask was a kind of creative chaos that could not even be denoted by common chemical formulas. This discovery of the role of the fuzzy and irregular transition state in chemical transformation was the final act of maturity for chemistry as science—which is not the same as ultimate wisdom, of course. What we can learn from chemistry is how the evasive and fleeting state of confusion (thought) creates certainty (language).

Should we wait until neurophysiology provides us with some kind of a device to observe the thought? This is a terrifying prospect for a human being who will turn into a simple screw of the social machine, so that the pipe dreams of Joseph Stalin would become reality overnight. Fortunately, there is a big snag for the physiology: the brains of the poor mice are split open to researchers, but mice do not think the way humans do, if they think at all. The brains of the humans—the last wilderness on earth waiting for a bulldozer—are for a while relatively protected, unless spilled out electronically.

There are two areas of chemical reality. The first one includes the stable terminal objects such as molecules (atoms are not always stable). The language for verbal one-to-one description of molecules of any size and structure is known as chemical nomenclature [3]. It can be found in any textbook of organic chemistry. In principle, it is similar to a system of rules and conventions used to identify the appearance of an animal in zoology, a plant in botany, or a human appearance in criminology, but with a substantial difference: the atomic composition and the connections between atoms can be completely extracted from the linear verbal description and *vice versa* because of a one-to-one correspondence between them, although molecular structure is typically non-linear. As I repeated many times [2], this unnoticed elephant in the room is well worth attention of linguistics and semantics

The second area comprises the chemical change, i.e., variations and transformations of chemical composition and structure. The chemical names are all nouns, but the terms of chemical dynamics are mostly either verbs or related verb-derived nouns, (like **to substitute** or **the substitution**).

There is another subtle but important aspect of Chemicalese. If a chemical paper (and for that matter any scientific paper) contains a description of an experiment, it is done in a particular, significantly standardized language which, like the language of chemical nomenclature, is designed to ensure the exact reproduction of the experiment by any other chemist, as the following fragment [4] illustrates:

Exp. 4. *Reaction of Naphthazarin (3) with Cyclohexa-1,3-diene*

To a solution of naphthazarin (**3**) (1.9 g, 10 mmol) in toluene (40 cm³) was added cyclohexa-1,3-diene (2.43 g, 30 mmol). The mixture was heated at reflux under argon for 3 days. After removal of the solvent and residual diene by evaporation, the crude cycloadduct (2.62 g) was obtained.

Dr. Jonathan Miller's home page, from which I quote, is a delightful induction into the atmosphere of organic chemistry.

An especially concise style of experiment description is used in *Chemical Abstracts*. This kind of language is intentionally primitive as compared with the more sophisticated (although dry enough) language of chemical theory. The latter, however, loses all its luster against extremes of Legalese and Greenspanese at the high end of the art of obfuscation. Anyway, the rest of the chemical paper—introduction, review of literature, discussion, and conclusion—is not as rigid as the experimental part.

As a stalker of the invisible, I limit my linguistic interests to human language in its earlier stages, when it was emerging from the hypothetical protolanguage Nean [2B] as a no-frills means of communicating information in a live coverage style. We can see a reflection of this stage in the development of language by infants and little children.

By definition, information is conveyed if a message is expected with sufficiently low probability, such as about appearance of a predator, prey, or a loss of a hunter. The language of chemical experiment is a good model of the early evolutionary stage when the things are conveyed typically only if there are alternatives. I see the upper end of this particular stage as the emergence of plans, desires, myths, and tales describing **imaginary** or **unobservable** events in a maximally simplified (from modern point of view) matter-of-fact language.

It is rarely possible to translate good poetry. Nevertheless, Ivan Bunin's famous translation of Henry Longfellow's *Hiawatha* into Russian was regarded by some as better than the original. I explain its success by the descriptive, explicit, and universally human nature of the mythological material.

Following the example of chemistry, let us call the atoms of thought **ideas** and acknowledge that they can be of two kinds (innumerable literature has been piling up since times immemorial). One kind comprises the terminal ideas that stand for (mean, denote, signify, relate to) individual objects: **dog, pine, man, shadow**, at which we can point a finger. Qualities and quantities, like **red, big, slow**, form bonds with them but are not material in the same sense **dog Spot** is. Neither are verbs, like **run, sit, eat**. They all belong to the second kind, together with other ideas like **from, inside, under**. I am not ready to suggest any terminology except **primary** and **applied** ideas. **The give** and **the to** in the Example with which this paper starts are applied ideas, invisible *per se*. Thought is a set of ideas. A thought itself can be an idea in another, more complex thought.

4. THE GIVE AS AN IDEA

The give, which I was looking for in the Egyptian wall painting, is something that I do not know what it is *per se*. It occupies a place in my mental construct involving other components, which unlike **the give** are directly observable and belong to the first kind. It has some relation to the verb **give**. No wonder I cannot see **the give** because it is an applied idea—as applied as the paint to the wall of Horemheb’s tomb. We need some substrate to apply it to.

The following is a tentative imitation of a chemist’s approach to thought as a molecule. This parallels the approach of Pattern Theory [5] in which atoms are called **generators** and molecules are **configurations**. In addition to that, Pattern Theory systematizes configurations and their transformations as patterns, which chemistry also does.

Imagine—departing from Egyptian paintings—that we are watching a real life or soap opera episode with **Ken (K)** and **Lucy (L)**, two people we can see and represent as primary ideas. **Ken** is **giving (g , applied) Money (M**: a bag of collectible quarters, also a primary) to **Lucy** right before our eyes, from hand to hand.

This is how the episode could be described in Nean [1B]:

**Ken. Lucy. Ken Money. Ken give. Ken Money. give Money.
give Lucy. give Money. Money Lucy. Money Lucy. Lucy Money.**

Do not underestimate the raw expressive power of Nean, rich enough to do even without the verb **give**:

Ken Money. Ken Money. Ken Lucy. Ken. Lucy Money. Lucy Money.

Something like Nean is used by sports commentators, especially for the fast moving soccer ball passed from a player to player: “Pele. Didi. Pele again. Didi. Pele.”

Used in such manner Nean has no problem with differentiating between the donor and the acceptor if the narrator and the listener speak the same dialect of Nean. If Lucy was the donor, we would start with **Lucy Money** and end with **Ken Money**. The natural temporal flow of speech in the Nean grammar is the verb tense marker even without the verb.

From my perch, Nean represents the very moment of conception of the verb and tense categories, as the old chemists used to say, *in statu nascendi*. A linguist could say that **Money** performs both noun and verb functions, quite natural for English, as the word **hand** does. So to speak, **Ken monies Lucy**. Compare with hypothetical **Ken hands his hand to Lucy** or **Ken clubs a lion with a club**. While the first is ambiguous (touches? offers? proposes?), the second is pragmatically unambiguous even as **Ken club lion** or **lion club Ken**.

There could be a different solution for differentiating between **Ken kill lion** and **lion kill Ken**, as well as **Ken break bone** and **Bone break Ken**: to add semantic markers of distinction between a human and an animal, as well as animate and inanimate, or even between long and short, flat and round, etc. The nominal classes of [Swahili](#) and the hierarchy of nouns and the classificatory verb stems of [Navajo](#) are examples. The evidence of the original fusion of syntax and semantics is also seen in the noun classifiers of [Chinese](#) (“[measure words](#)”) and counting suffixes of [Japanese](#).

Semantic markers seem natural if the language evolves from overgeneralization (which happens with infants, too) when, for example, not only all liquids, but also some far-reaching chains of associations can have the same sign.

In Sumerian, for example [6]:

a, e₄: n., water; watercourse, canal; seminal fluid; offspring; father; tears; flood.

ú: n., plant; vegetable; grass; food; bread; pasture; load

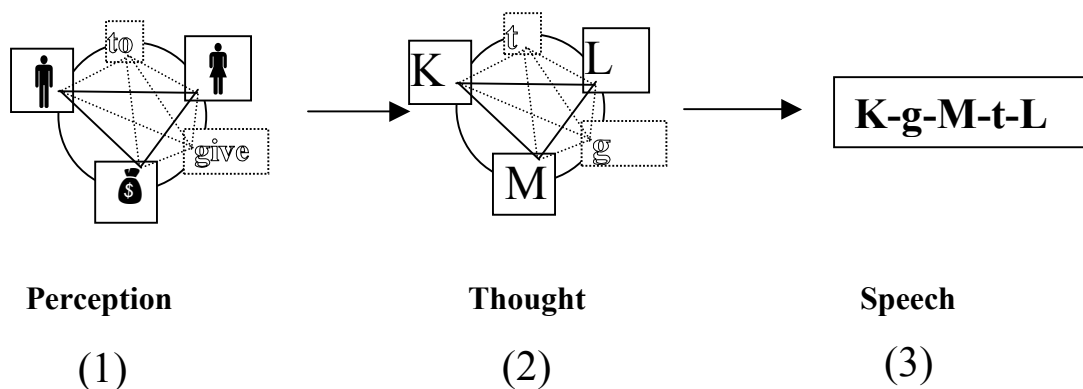
See an interesting discussion of this subject in [6].

To speculate further, the relatively redundant agreement, as between nouns and adjectives in Russian and Swahili, may be an artifact of Nean. I would even dare to suggest that all the markers come from the primary ideas of the inherently redundant Nean. They probably evolved as means of speeding up the transfer of information, which was, I think, the main driving force of early language evolution, quite similarly to the evolution of species, in modern terms, and evolution of technology in modern times.

Next I will try to develop a chemistry-friendly representation of the non-linear thought that generates the linear utterance **K-g-M-t-L**, in which the letters are atomic symbols for words.

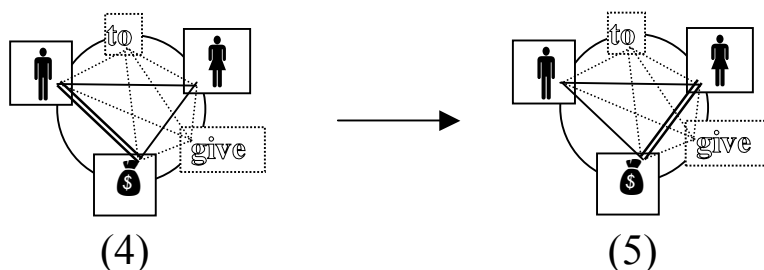
I regard the pre-historic thought as a simple **aggregate** of a few ideas that are **all interconnected** just because they are together by some criterion, namely, belonging to the same thought reflecting the same spatial or temporal closeness. One could ponder whether the topology of thought is a full graph or the zero topology of a (simple) set in which elements are labeled, but neither connected nor have duplicates.

Set with duplicates is called bag. Set is what collectors display in a collection where items do not have duplicates or as words in a dictionary. One can also remark that if thought is just a set, animals think too, which I would not dispute. Humans, however, went much farther, but how far—we will never measure until we know the starting point.



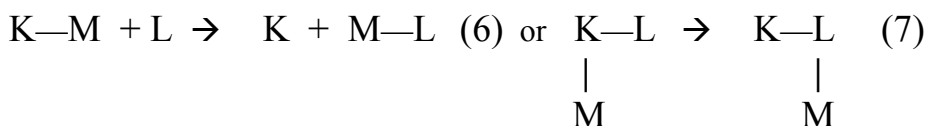
We can point to the primary and stable **K**, **L**, and **M**, but not to **give** or **to**, unless in speech. Let us tentatively reserve some space for the latter two in the perception and thought, denoting their ghostly presence with outline font and their connections with dotted lines. The lines mean that **all** the atoms of thought are **more or less** connected in the object of thought, although we may not know how exactly. This point is what distinguishes the approach of Pattern Theory [5] and chemistry to structures. The structure, whether molecule, thought, or utterance, is a **configuration**, while pattern is, approximately, a class of configurations, for which the rules of similarity within the class are formulated.

In order to notice the action, we need to look at the event at least twice:



Having done that we can, at last, notice that there are some changing connections between the ideas, invisible in a static picture. The strong (double line) bond between **M** and **K** (4) moves to the position between **M** and **L** (5). To put it differently, **M** moves (migrates) from **K** to **L**.

In a chemical style notation:



This transformation is a pattern, applicable to many primary ideas, and pattern is an **overgeneralization**, much exceeding in its range the Sumerian notion a (**water**, etc.).

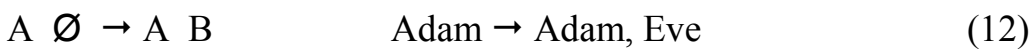
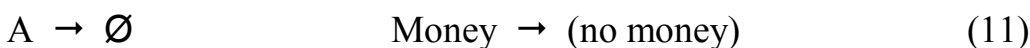
Focusing on the points of change, we come to the “chemical” equation, in which the broken lines symbolize the transition state:



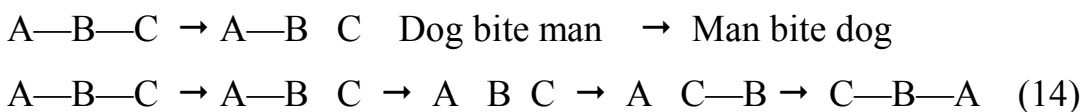
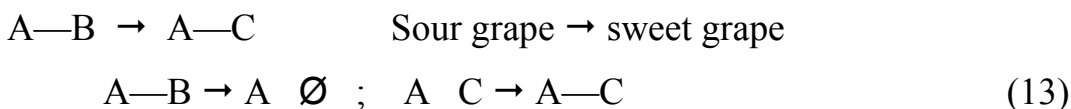
Chemical transformations in an isolated system are reversible and the transition state can lead to either the initial or the final state. The uncertainty can be reflected in language:

Ken is considering giving money to Lucy. Or even: **K and L fight for M.** For an irreversible action, the single arrow indicates the direction of the transformation.

Regarding transformations, the principle of atomism means that they can be decomposed into simple and further indivisible steps. In the spirit of chemistry we can define **simple** (atomic) acts as occurring within a topological neighborhood. The **complex** acts can be reduced to a sequence of simple ones. This principle strongly limits the variety of simple actions:



Even already simple enough transformations can be represented as a sequence of the above simple steps:



There are **maximum four** atomic components of a change: formation (1) and breakup (2) of a single bond and appearance (3) and disappearance (4) of a generator. Jumping to thought, a simple thought **P** (the stem cell of all thoughts) is, at most, a quartet:

$$\mathbf{P} = \{ \mathbf{A}, \mathbf{B}, \mathbf{A—B}, \rightarrow \}, \quad (15)$$

where **A** and **B** are ideas, **A—B** is a bond between them, and arrow $\rightarrow$ is a coordinate of change, i.e., the locus of change, for example, appearance/disappearance of an atomic idea or locking/breakup of the bond. The arrow, for which **pointer** is a better term, **points** to the changing component by connecting the initial and the final states of an act of change. There are at least two possible notations for a change (16, 17):

$$\mathbf{A—B} \rightarrow \mathbf{A} \quad \text{Ken Lucy} \rightarrow \text{Ken (alone)} \quad (16)$$

$$\begin{array}{c} \mathbf{A—B} \\ \uparrow \end{array}$$

$$\mathbf{A—B} \rightarrow \mathbf{A—C} \quad \text{Sour grape} \rightarrow \text{sweet grape} \quad (17)$$

$$\begin{array}{c} \mathbf{A—B}, \mathbf{A} \quad \mathbf{C} \\ \uparrow \quad \uparrow \end{array}$$

The arrow (pointer) is, in my opinion, the precursor of the verb. In early steps of language evolution it was probably a single sound or a gesture signifying or symbolizing action (the theories of gestural origin of language origin are vigorous today). It would be used only if the context was obscure.

A—B

$\diagdown \quad \diagup$
C

(18)

Note that the “atomic” configuration **A B C** in (14) makes no sense in linear speech where the adjacency is already a bond. Neither does a cyclic configuration (18), equally impossible in the linear speech. Both can be seen as short-living unstable stages of the process of linearization

of thought into speech. What is wrong as speech is OK as thought.

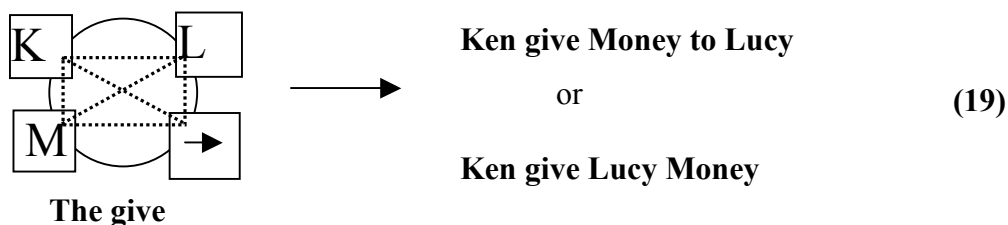
Transition state in chemistry is anything but state. It is a **process** which can be approximated by a sequence of elementary steps, not in all-or-nothing fashion, but as a continuously changing distribution of bonds of variable strength. I must emphasize that the chemical transition state is still as little observable as the thought, although the situation could change. What helps, is that the elementary steps are always **local**.

5. FROM THE POINTER TO THE VERB

Strictly speaking, **the give** (the thought, not the verb) consists of four elements:

$$\{ \mathbf{K}, \mathbf{M}, \mathbf{L}, \rightarrow \}$$

I hypothesize that the thought **give** is a transition configuration between the representation of the perceived scene in the mind (which is outside linguistics) and the utterance that conveys the thought.



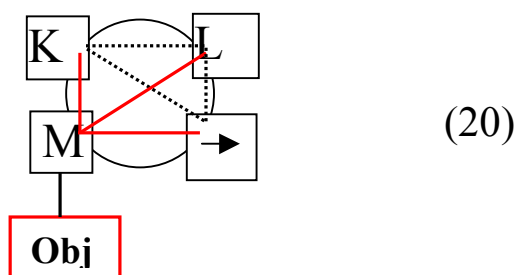
We still cannot put a finger on the arrow, but whatever it is, the four-component thought transition state is highly ambiguous: it can be linearized into utterance in $4!=24$ ways. The alternative form **Ken give Lucy Money** is unambiguous only because **Lucy** is animate and **Money** is not, which we know, but, unlike in Swahili, do not mark. **Ken put**

box bag is highly ambiguous because box and bag can be put into each other. In a language similar to Navajo and more elaborate than Swahili, the difference can be marked by verbal object suffixes, and it in fact is marked in Navajo [7], where bag and box require different roots for verb **give**: *ni'a* for give box and *niyí* for give bag. The ambiguity can be eliminated if the position in the four-word sequence alone signifies the semantic role, which even the morphologically skimpy English language does relatively rarely.

Grammar, from the chemist's point of view, is a way (more accurately, a **catalyst**) to reduce the stress of the transition state. In terms of chemistry, it gives a preference for linearizing the thought in a particular way, reducing the entropy of choice, although the grammar can often be violated without detriment to understanding. The post-Nean grammar works by either attaching various markers or freezing the word order, or both.

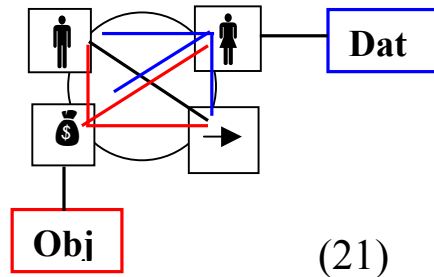
While the word order has its limits (only not more than three ideas form a linear neighborhood **A—B—C**), even a single morphological marker can help a lot.

If we attach a marker (in speech, not in thought!) of the direct object (**Obj**) to **Money**, for example, all three its transition bonds (red) are not needed anymore:



Money, with its marker (infix or case ending), can be now placed anywhere in the utterance, although a certain predominant word order characterizes all languages. This ordering is necessary because the remaining transition triangle **K, L, g** is still too ambiguous to linearize.

If we add a marker for the indirect object (**L**) , in the form of a dative case (**21**) or a preposition (**to**) , the only remaining ambiguity is the relative positions of **K** and **g**.



It can be disambiguated (I hate this word!) in two ways: by marking either the subject or the pointer.

Japanese has a prominent marker for the subject (**-ga**) , as well as for both objects (**-o** and **-ni**) , plus a topic marker (**-wa**). Nevertheless, the end position of the verb, which is also often marked with a suffix (**-mas** , **-suru** , **-iru**, etc.) is fixed. Hungarian, which marks the objects (with **-t** and **-nek**) but not the subject, has no fixed word order, probably because the verb, **lexically different from noun**, is almost always marked. The Japanese sentence looks like a single word with fixed positions for all components, clearly marked. Swahili resolves the ambiguity by neatly packing all semantic object markers into the verb, already loaded with tense, but it still needs an **SVO** word order to keep both **S** and **O** close to **V**. Russian typically marks all it can mark but the subject, so that the unmarkedness of the subject is the marker itself, and Russian, like Hungarian, has a very free word order. Navajo lists the nouns in the very beginning in a certain order, according to their rank of animation:

Human → Infant/Big Animal → Medium-size Animal → Small Animal → Natural Force → Abstraction

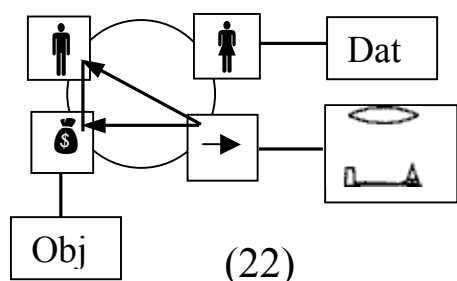
Such differences between the languages could be a fossil pit for paleontology of language.

How can we mark an arrow which, theoretically, is always the same and should be assigned a single word? Whatever marker we attach to the same unique word, it will be

just another unique word, which, by the way, does not need any marking. The **verb** is just the lexical marker of the pointer, which is not the only way to do it because **the verb**, strictly speaking, **is not necessary**. Parts of speech, syllables, words—are they a matter of convention? Certainly not in English. But together with some linguists I strongly suspect that modern linguistics as the science of language bends, trembles, and groans under the heavy Indo-European burden imposed by Panini's grammar of Sanskrit. The ancient speaker of the emerging language never knew what terms the grammarians would use afterwards.

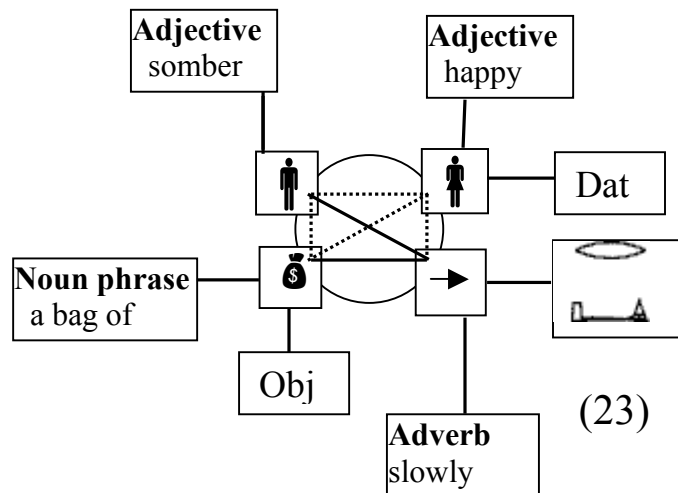
As a free-thinker, I feel a great deal of mistrust when the linguists speak about **SOV** word order when the verb is **always** at the end. This is the **verb-last** order, people!

Language evolved as patterns of thought and patterns of its linearization, which, as we see, can be done in a vast variety of ways. Neither word nor verb is a universal concept of language. Furthermore, the patterns of thought are representations of patterns of the world—the idea clearly expressed by Spinoza—but all we know about the world is our representation of it. The thought in the following interlingual form **(22)** is, probably, sufficient to translate it into any language equilibrated with a relatively simple and stable reality. The arrow here points to **K** and **M**, which means that Ken has to part with his Money and Lucy is ready to accept the bag (we don't know if she will) but not necessarily Ken himself. The Egyptian hieroglyph **rdi** is chosen here to represent the idea of **give**.



Why then did the verbs develop at all if they were not necessary? This is something paleolinguistics should be concerned with. It is a pure speculation on my part, but I suggest that the patterns of human thought arose from the use of tools, which is rather atypical of animals. To kill, eat, mate, share, cheat, and fight required two components of thought. The tools and the hands to use them in various ways were, probably, responsible

for the development of three- and four-component thoughts. Much more can be speculated on this platform, but I better stop.



Structure (23) gives some hints how thought could further develop complexity, while preserving its ancient core and compatibility with linearization, but it is beyond the scope of my strictly provisional paper.

5. NOTE ON **GIVE** IN NAVAJO (in which I am by no means an expert).

Polysynthetic (a chemistry-smelling term!) languages, like Navajo, linearize thought in a very strange for Europeans, but basically natural way: the markers are attached not to the nouns, but incorporated into the “verb” and show who or what does what to whom or to what in what manner. In other words, the “verb” is the skeletal phrase, a linearized pattern of thought, preceded by the unmarked nouns [7]:

Łééchaq’í mósí yinoolchéél
 dog cat it-is-chasing-it
 the dog is chasing the cat

Abandoning the firm chemical ground under my feet, I would say that the above example looks to me as the embryonic “stem cell” for all languages.

The structure of Navajo seems overwhelmingly complicated, primarily because of the prohibiting complexity of the available printed dictionaries, but with some doggedness a chemist can see how it works. The language of chemical nomenclature [3] is a close relative of polysynthetic languages. Example [4]: 1,4,4a,9a-*tetrahydro-5,8-dihydroxy-1,4-ethano-9,10-anthraquinone*. See [4] (Exp. 4) for what it depicts.

It is my uneducated guess that the elaborate polysynthetic languages, like Navajo (not too many of them are well studied), do not have verbs in Indo-European sense. Instead, they use **ideograms**, similar to Egyptian and Chinese ones, as well as to the German compound words, built not from graphic elements but from phonemes. The pictorial nature of Navajo (“mental television”) was noted by the native speakers.

Why are tribal languages often very elaborate and sophisticated? Because thousands of years of stable ordered life with little social and political turmoil are beneficial for the slow evolution of complex patterns of culture. Just compare with the dumbed down, primitive, fragmented, kaleidoscopic, superficial, ephemeral, hectic, and hysterical culture of the twenty-second century.

The Navajo “verb” is a whole proposition [7A,B] , which means that it is actually the entire phrase in which the primary components (Subject, Direct Object, Indirect Object) are always the same standardized elements, similar to pronouns and, if you wish, to the suffixes of classes in chemical nomenclature: **hydroxy** or **ol** for alcohol, **di** for dual plural, **on** for $>\text{C}=\text{O}$ group, *etc.* The primary elements are listed in the very beginning, usually without markers. By analogy with Japanese, where the topic of the proposition is a **wa**-ending noun or noun group in the very beginning, I would call Navajo a **polytopical** language: all its nouns are the participants of the action/state, and not just one of them, as in Japanese. They are like listed roles and actors in titles with which older

movies begin—but the stars go first—giving the clue to the components of the subsequent “verb.”

One can imagine a process by which an ancient polysynthetic language, with not fully differentiated syntax and semantics, further evolves into a more segmented one, in which typical (for most of us) nouns develop from the anterior protagonist list of the sentence, typical verb develops from the posterior “action” part, and typical adverbs, adjectives, and pronouns scatter from what is in between, releasing also some nouns frozen into the “verb.” By backtracking we can descend to more primitive forms in which noun and verb, the primary and the applied components, are not differentiated. In this way we can see relation between Navajo, Swahili, Japanese, and Indo-European languages. All languages are equal under Thought, but some are more equal than others.

The noun classifiers in Chinese and classificatory verb stems in Navajo look like the same linguistic phenomenon connecting the two languages across the Pacific, which is not quite surprising after all if we accept the Dene-Caucasian hypothesis [8]. There is, however, much more similarity between Chinese and Navajo in the very nature of close relation between thought and speech, topicalization, and tightly fused sentence, while classifiers seem to be a more ancient phenomenon. Both languages use ideograms: one for writing, the other for speech. Naturally, Chinese needs phonetic elements in its ideograms, which Navajo has *gratis*. Both are poorly equipped for representing new sounds and concepts. But the sparse, lean English-like Chinese needs more of context.

The verb in the Euro-centric sense is always at the very end of the Navajo “verb,” where it signifies a very abstract idea of a pattern of change (for example, simple horizontal movement of Direct Object from Subject to Indirect Object, which is called **migration** in chemistry) and a more concrete but abstract enough situation to which it is applied (something in an open container), plus the very elaborate dynamics of the process (for example, tense, mode, and aspect). This is what **nikaah** (to give something in an open container, momentaneous imperfect form, 3rd person singular, if I am not mistaken, in Example means, although this entire Note is a gross simplification. The stem of verb

nikaah is **KÁ** [7A, p. 294; 7C] , which means an object or substance in an open container. Nevertheless, if one can handle chemical complexity, so one can manage the complexity of Navajo—the language which is an adventure in itself. Chemistry becomes simple in simple cases and so does Navajo. The problems, however, arise when we apply a complex language to a complex reality, in both chemistry and linguistics. The slow communication makes little sense, unless in correspondence between philosophers.

The wonderful worlds of Navajo and Chinese leave open unique windows into human thought, but they should be better left to another opportunity of discussing Nean and kinetic aspects of language evolution.

7. CONCLUDING REMARKS

Although I ignored here the Hymalayas of related literature, one major linguistic movement that starts with a natural-scientific analysis of an event, **before it becomes a thought**, must be mentioned. It is associated with the names of George Lakoff, Mark Johnson, and other enthusiasts of cognitive linguistics, to whom a chemist can feel an instinctive attraction [2B]. As Laura Janda writes,

From the very beginning, cognitive linguistics has been a refuge for linguists who are intimately acquainted with real language data and have a profound respect for empirical methods [9].

There are, however, even closer kindred souls for a chemist who asks “what if the words were indeed atoms?” Leonard Talmy [10] develops in his cognitive semantics the entire directly observable **physics** of the world from the point of view of its linearization into speech. This seems to me a remarkably innovative and tall idea, to which the chemist alone would not arrive, but could *post factum* formulate it as: **the things have geometrical, physical, chemical and other properties, but they also have a property**

of being told about **in a language**. The languages of Navajo type open a window into the fascinating process of language evolution driven by the general **kinetic properties** of the world, noticed first by René Thom [11, 2B].

My first main idea is that **all** components of human thought, i.e., primary and applied ideas, are connected, although some are more connected than others. The connections may vary over the short time while the thought resides in the mind before either being abandoned, or dumped to memory, or expressed in speech or action. This assumption of an attention window strongly limits the size of the thought. *Ars longa, vita brevis*. The language of art, science, and culture may be long, but we do not have time or memory space for long thoughts.

How much chemistry is in this strange conjecture? Quite a lot, I believe. All atoms interact at a short distance and either attract or repel each other, with repulsion predominant at a very close distance. This is how the proteins take their shape by minimizing the overall strain. I assume that all ideas in the thought are in the neighborhood of each other. **The same is observed in speech** and this is how the sentence takes its shape: “**Speech in observed the is same**” is utterly strained, while “**In speech the same is observed**” is much less so.

The local principles alone are clearly insufficient for ordering modern sophisticated language, which is a result of a long cultural evolution influenced by writing and public oration. It is the language of style and culture, not just of the thought. But they might be sufficient to fill the gap between the protolanguage and the cultivated language of writers and philosophers with its long-distance interaction and central planning of the composition. They might also be sufficient for the spontaneous language stimulated by a fast developing event. Linguistics as a natural science must be the science of time, as chemistry dominated by kinetics is.

There is no contradiction between thinking in language or in a mysterious **language of thought**. When we think in language, for example, internally formulate (“think over”)

what we want to say before actually saying that, we simply broadcast the silently prepared and memorized text. When we see a person who is in a danger of being hit by a car and want to warn him or her, we do not have time to think and are in the same position an ancient man was while watching a lion behind the back of his companion hunter.

Linguistics as natural science cannot have sharp borders. But let us deal only with the problems related to thinking and generating speech. If we decided to deal also with actions, we would come to a firm conclusion that mice think, as all animals do, and this would make some of us feel very uncomfortable while eating them.

My second main idea (partly resonating with the ideas of Sergei Starostin [8]) is that in order to understand language as a natural phenomenon we have (1) to start with very **small** and primitive systems, (2) to see how a **small** evolutionary step can be made, and (3) to apply the procedure repeatedly not only up to present, but also up to a not too remote **future** of language, so that we could check the theory. If this reminds of the method of mathematical induction or of classical Darwinism, I absolutely do not mind. The language acquisition by children does not recapitulate language origin. What both represent is evolution of complexity from simplicity by simplicity.

WISPERING TO A HORSE: My purpose was to test if I would be able to cross a river over a thin ice from the thought side to the speech side, or, one could say, to circumnavigate the brain from the right to the left hemisphere, in my chemical rubber boots. I am far from my goal and not even sure that I am crossing the right river and even know the right from left. Later I will, probably, give it another try by applying the principles stated here to the lingo-chemical system of *The Tale of Three Little Pigs*, which would supply the component missing here: pragmatics, i.e. the naïve physics of the world. But do I really know what I mean by what I say? As I stated here and in previous e-papers, to understand means to tell somebody else. In a short story by Chekhov, the man tells his troubles to a horse.

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What if the words were indeed atoms?

SALT: THE INCREMENTAL CHEMISTRY OF LANGUAGE ACQUISITION

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2005

Abstract

This e-paper continues the examination of language as a quasi-molecular system from the point of view of a chemist who happens to ask, “What if the words were atoms?” Ideas of Pattern Theory (Ulf Grenander) are used as a kind of generalized chemistry. The Hungarian folktale *A Só* (Salt) is represented as a sequence of syllabic triplets. Small portions of the text are fed to a quasi-chemical reactor working according previously described principles of acquisition and categorization of generators. The gradual development of categorization and aggregates of syllables is illustrated.

SALT: THE INCREMENTAL CHEMISTRY OF LANGUAGE ACQUISITION

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2005



Draft

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Introduction

This e-paper directly follows and complements the previous one [1], the introduction, literature review, content, and discussion of which will not be repeated here except for two notes.

First, my primary subject of interest is atomistic systems in general, within the framework of Ulf Grenander's Pattern Theory [2,3], which encompasses both molecules and utterances, as well as practically everything perceived by senses and/or reason.

Second, my previous attempt to analyze a fragment of the Hungarian folk tale *A só* (Salt) [4] in the same manner as *The Three Little Pigs*, i.e., regarding words as generators [1], showed no promise because of the agglutinative nature of Hungarian.

There were too few words that could be centers for categorization and generator acquisition because most functional morphemes stayed appended within the word limits. Here I attempt to analyze the same text, taking **syllables** as generators and gradually adding sentences into the focus of attention.

The choice of text was dictated by its availability on the Web in both text and audio forms, as well as by its cultural origins. The folk tale is a perfect window into the language because of its transparency, simplicity of context, universality of human experience, and repetitions. The folk tales are relics of the earlier stages of language evolution when the complexity of life and ideas did not press hard on the language, extruding multilevel sculptures of wired together fragments that needed a long attention span and training to understand. The tales correspond to the bygone era when the entire society spoke the same language. A folk tale is like a book of one page, so that you do not need turning pages in order to follow the plot, while keeping in mind what was on the previous pages, now out of sight. The tale is designed to be told, not written. Moreover, it is designed for children. Repetition is the mother of learning.

I am not a speaker of Hungarian. My knowledge of the language is limited to superficial familiarity with grammar and some experience with translating into Russian the poetry of the highly original, passionate, and innovative Hungarian poet Endre Ady (1877-1919).

I choose Hungarian because it seems to be the opposite of English, has the phonetic system of writing, a fixed stress, a very rational, slim, and non-redundant grammar, and could **not** be understood by most readers of this paper, if such be found. Therefore, the aspects of structure, which are in the heart of Pattern Theory, as well as chemistry, will not be obstructed by cultural and semantic predisposition. With Hungarian, the aspects of grammar and alternation will not be too overpowering, as it could happen, for example, with much more exuberant Russian or Turkish.

The Hungarian syllables should be perceived here as small labeled atomistic objects capable of forming linear chains. As a chemist would say, the syllables are

monomers and the phrases are polymers, while phonemes are the true atoms of language. Oligomers, i.e., short linear fragments, are called here **blocks**.

I myself, however, cannot be free of bias. I have a personal impression of Hungarian as a very elegant, graceful, and beautiful creation of language evolution, although modern special texts—probably, in any language—might make a different impression.

Regardless of that, it seems that the fragmentation of speech into syllables is as arbitrary as division into words. I feel, for example, a big discomfort when the numerous forms of the noun in Hungarian and Finnish are considered cases because I see the endings as just postpositions written together with the root and other markers.

The problems with hyphenation that arise in languages with long words, such as Russian and Hungarian, can be very complicated. The syllable segmentation that I use here is arbitrary, but biased by my instinctive desire to bring the syllable as close to the morpheme as possible. One cannot know what a morpheme is in an unfamiliar language, but I cannot ignore my own knowledge. For example, the old word *bátyámuram*, to address an older person, literally “my brother my lord”, splits phonetically, with my Russian phonetic habits, into *bá-tyá-mu-ram*, but I see its morphologic constituents as *bá-tyám ur-am* (or, *báty-ám* or, splitting the long *á*, *bá-tya-am*).

I doubt there is the “right” way to segment speech in a written text. The ancient scribes did not know the space between the words and modern Chinese does without it, being naturally syllabic. Therefore, I just leave it as I choose because I am not interested here in the factual truth, often disputed in linguistics, but in the operational truth: I don’t know what it is, but let us see how “it” behaves. Ultimately, I believe only in phonological facts but I am not qualified to represent them. The “facts” of the written language are just conventions, more or less reasonable. The sound is a physical fact.

I inserted the pauses from the available soundtrack. In most cases, the pause coincides with a punctuation mark, but not always. The STOP is the full stop.

I am convinced in the leading role of prosody and pitch in early language acquisition by infants, on which there is a large and growing body of solid experimental work, off the battlefields of formal linguistics. I mark the stressed syllables by capitalization, but I realize that this is somewhat arbitrary, too. Some longer Hungarian

words have an additional stress and the sentence often starts with a raised pitch. Should I mark all monosyllabic words stressed? I simply do not know. To complicate the picture, in Hungarian, as in Russian, a single consonant can be a morpheme, which is more typical for polysynthetic languages. Such a lean loner may not be a legitimate syllable, but it is definitely a generator in the sense of Pattern Theory [2,3].

The descent to the level of phonemes is an intriguing task, for which Italian is a good medium. Until then, I take the syllable segmentation for granted. Therefore, I do not pay attention to the generator identification here, unless some special cases of markers.

Illustrations and discussion

The following is a description of an experiment. By no means is it a computer simulation of some realistic object. This is only an illustration of principles. THIS IS ONLY A TEST. I use computer only for the purpose of representation of the text and sorting out the results. The MATLAB output is further easily converted into tables with MS Word Table functions.

If this is an experiment, we have to describe its subject participant. I prefer to call the subject **robot-child**. It is an imaginary system that can be described only approximately and vaguely. It possesses tunable memory and attention span and is supposed to learn something from the input.

The strings of syllables are fed into the robot-child's mind (which I see as a kind of a chemical reactor) where they are digested into overlapping triplets. It is important that the **original string is not remembered**, but its stable repetitive fragments, as well as new knowledge, could be.

The memory stores:

1. The syllables.
2. Relatively stable bonds of some of the syllables with the neighbors in the original strings.
3. Classes (categories) obtained as result of simple local operations.
4. Some non-syllabic generators as grammar markers.

The chemistry of the mind of the robot-child is defined by simple local rules. For all the explanations see [1], which is absolutely necessary for understanding this paper.

At each step, a sentence from the text is added to all the previous ones and the total is analyzed as a whole. This is not exactly what happens during the language acquisition, but further modifications in the direction of realism are possible. By the realism I mean here a fast forgetting of most details of the freshly perceived utterances.

Step 1

MATLAB input: P1=char ('**STOP**', 'volt', '**EDY**', 'szer', 'egy', '**Ö**', 'reg', '**KI**', 'rály', '**PAUSE**', 's', '**HÁ**', 'rom', 'szép', '**LE**', 'ány', 'a', '**STOP**'); P=P1;

Table 1

	LEFT	N	Generator	RIGHT	
1	#	2	STOP	volt	
2	STOP	1	volt	EDY	
3	volt	1	EDY	szer	
4	EDY	1	szer	egy	
5	szer	1	egy	Ö	
6	egy	1	Ö	reg	
7	Ö	1	reg	KI	
8	reg	1	KI	rály	
9	KI	1	rály	PAUSE	

10	rály	1	PAUSE	s	
11	PAUSE	1	s	HÁ	
12	s	1	HÁ	rom	
13	HÁ	1	rom	szép	
14	rom	1	szép	LE	
15	szép	1	LE	ány	
16	LE	1	ány	a	
17	ány	1	a	STOP	

The numbers in the third column are occurrences.

The table has no double entries. STOP and PAUSE are ignored.

Step 2

P2 = char('az', 'Ö', 'reg', 'KI', 'rály', 'SZE', 'ret', 'te', 'VOL', 'na', 'mind', 'a', 'HÁ', 'rom', 'LE', 'ány', 'át', 'FÉRJ', 'hez', 'AD', 'ni', 'STOP'); P = strvcat (P1, P2);

Table 2

	LEFT		G	RIGHT
1	a	3	STOP	az
2	STOP	1	volt	EDY
3	volt	1	EDY	szer
4	EDY	1	szer	egy
5	szer	1	egy	Ö
6	az, egy	2	Ö	2-reg
7	2-Ö	2	reg	2-KI
8	2-reg	2	KI	2-rály
9	2-KI	2	rály	PAUSE, SZE
10	rály	1	PAUSE	s
11	PAUSE	1	s	HÁ
12	a, s	2	HÁ	2-rom
13	2-HÁ	2	rom	LE, szép
14	rom	1	szép	LE

15	rom, szép	2	LE	2-ány
16	2-LE	2	ány	a, át
17	mind, ány	2	a	HÁ, STOP
18	STOP	1	az	Ö
19	rály	1	SZE	ret
20	SZE	1	ret	te
21	ret	1	te	VOL
22	te	1	VOL	na
23	VOL	1	na	mind
24	na	1	mind	a
25	ány	1	át	FÉRJ
26	át	1	FÉRJ	hez
27	FÉRJ	1	hez	AD
28	hez	1	AD	ni
29	AD	1	ni	STOP

After **Step 2** we see multiple (double, to be exact) entries of some generators into the **Table**. Two “chemical” processes are, therefore, possible:

1. Class acquisition

Class (= category, pattern) *W* requires two or more different neighbors (A, B, C...) on one side of generator *X*.

NOTE: Letter *W* is chosen because it is not in Hungarian alphabet, except for foreign words.

No.	A, B, C	3	X	...
-----	---------	---	---	-----

No.	...	3	X	A, B, C
-----	-----	---	---	---------

$$\{A, B, C\} - X \Rightarrow W - X$$

$$\{A, B, C\} \Leftrightarrow W$$

$$X - \{A, B, C\} \Rightarrow W - X$$

$$\{A, B, C\} \Leftrightarrow W$$

2. Bond A-X acquisition

Bond A-X requires two or more occurrences of the same neighbor A of X .

No	...	2	X	2-A
----	-----	---	---	-----

No	2-A	2	X	...
----	-----	---	---	-----

$$\{X, A\} \Leftrightarrow X - A$$

$$\{A, X\} \Leftrightarrow A - X$$

Step 2 produces new classes from the following lines of the Table 2
(*** stands for non-participating generators) :

6	az, egy	2	Ö	***
---	---------	---	---	-----

15	rom, szép	2	LE	2-ány
----	-----------	---	----	-------

12	a, s	2	HÁ	
----	------	---	----	--

16	***	2	ány	a, át
----	-----	---	-----	-------

13	***	2	rom	LE, szép
----	-----	---	-----	----------

17	mind, ány	2	a	***
----	-----------	---	---	-----

W1 { az, egy } - Ö

W2 { a, s } - HÁ

W3 rom - { LE, szép }

W4 ány - { a, át }

W5 { mind, ány } - a

Step 2 produces new bonds from the following lines of Table 2:

6	***	2	Ö	2-reg
7	2-Ö	2	reg	2-KI
8	2-reg	2	KI	2-rály
9	2-KI	2	rály	***

15	rom, szép	2	LE	2-ány
16	2-LE	2	ány	a, át

$\{\ddot{O}, \text{reg}\} \Leftrightarrow \ddot{O}\text{-reg}$; $\{\text{reg}, \text{KI}\} \Leftrightarrow \text{reg-KI}$; $\{\text{KI} + \text{rally}\} \Leftrightarrow \text{KI-rally}$;
 $\{\ddot{O}, \text{reg}, \text{KI}, \text{rally}\} \Leftrightarrow \ddot{O}\text{-reg-KI-rally}$; $\{\text{LE}, \text{ány}\} \Leftrightarrow \text{LE-ány}$;

Since LE and ány belong to classes W3 and W5 other equilibriums are possible :

$\{\text{LE}, \text{ány}\} \Leftrightarrow \text{LE-ány}$;

W6 rom- $\{\text{LE}, \text{szép}\} \Rightarrow \text{rom-}\{\text{LE-ány}, \text{szép}\}$

W7 $\{\text{mind}, \text{ány}\}\text{-a} \Rightarrow \{\text{mind}, \text{LE-ány}\}\text{-a}$

The further fate of newly formed bonds and classes depends on the function of memory: bonds, as well as classes will fade away unless strengthened by repetitions. The extremely limited and repetitive infant-addressed speech is essential for language acquisition. The limited environment of the infant (**the blessing of the poverty of stimulus**) satisfies this condition.

The folk tale like *Salt* is suitable for language expansion but not acquisition by infants. The child-addressed speech has been a subject of detailed investigation in many languages and its properties—almost no syntax, short phrases, pauses, and repetitions—make me think that if there is anything innate in language acquisition it is the Motherese, which sounds very much as Nean. For an introductory but rich in detail review, see [5]. Some Russian tales for children are very simple and repetitive, for example *Kolobok* (“Round Bun”) [6], which is one of the very first tales read to children in Russia.

It is easy to see that if the steps of processing *Salt* are continued, the content of the acquiring mind will soon become complicated. Its complexity does not exceed, however, that of grammar, which is easily manageable by a young mind. It is important to understand that such complex equilibriums are typical for chemical systems. They would completely paralyze all practical chemistry, as well as biochemistry of life, if not for one circumstance: **most of them are absolutely negligible** because either an equilibrium is

shifted practically toward one end or either the establishing of most equilibriums takes a very long, sometimes astronomical, time. In chemical reality, the content of the flask or living cell is processed before the equilibrium establishes, so that only a few fast-forming products are present. Life and industrial chemistry never come to equilibrium. Even in wine-making, achieving equilibrium during the maturation of the wine is just a costly dream.

I would dogmatize the principles of kinetics in human sciences in the following way:

We say what can be said faster.

We understand what can be understood faster.

We do what can be done faster.

Examples: we say stupid things, fear mathematics, and marry a wrong person.

The next question is how we can compute such systems where **kinetics and not thermodynamics** rules. They are not the same as what is understood by **dynamical systems**. As I believe, this is where the key to understanding the mind can be found.

I suspect that computational chemistry has made some progress in this area, which is outside my expertise, but I am not familiar with the literature at this point. I leave this question open, adding only that I believe that Ulf Grenander's GOLEM [3] is the right starting point because of its chemical properties. The only idea I would add is the kinetics.

It is not so difficult to program the succession of steps, but it is more difficult to include the kinetics because of problems with the structure of transition state. It is possibly complicated, but not hopeless. I am not prepared, however, at this stage to approach the entire problem of computation. The molecules compute the state of the system quite effectively, I can see how they do it, but without a new parallel hardware it would take astronomical time to simulate it on PC. In computational chemistry this type of problems is represented by **protein folding**.

The information about the state of the system, kinetic or not, can be fully represented by the **Q** and **A** matrix of Ulf Grenander [2,3]. Honestly, I am afraid that the

computation can only obscure the simplicity of basic ideas. In order to better illustrate them **incrementally**, I am adding the next step.

Step 3

P3 = char ('ez', 'nem', 'is', 'lett', '**VOL**', 'na', '**NE**', 'héz', 'mert', '**HÁ**', 'rom', '**OR**', 'szág', 'a', 'volt', '**PAUSE**', 'mind', 'a', '**HÁ**', 'rom', '**LE**', 'ány', 'á', 'ra', '**JUT**', 'ott', '**EDY**', 'egy', '**OR**', 'szág', '**STOP**'); P = strvcut (P1, P2, P3);

Table 3

1	a, ni	4	STOP	az, ez
2	STOP, a	2	volt	EDY, PAUSE
3	ott, volt	2	EDY	egy, szer
4	EDY	1	szer	egy
5	EDY, szer	2	egy	OR, Ö
6	az, egy	2	Ö	2-reg
7	2-Ö	2	reg	2-KI
8	2-reg	2	KI	2-rály
9	2-KI	2	rály	PAUSE, SZE
10	rály, volt	2	PAUSE	mind, s
11	PAUSE	1	s	HÁ
12	2-a, mert, s	4	HÁ	4-rom
13	4-HÁ	4	rom	2-LE, OR, szép
14	rom	1	szép	LE
15	2-rom, szép	3	LE	3-ány
16	3-LE	3	ány	a, á, át
17	2-mind, szág, ány	4	a	2-HÁ, STOP, volt
18	STOP	1	az	Ö
19	rály	1	SZE	ret

20	SZE	1	ret	te
21	ret	1	te	VOL
22	lett, te	2	VOL	2-na
23	2-VOL	2	na	NE, mind
24	PAUSE, na	2	mind	2-a
25	ány	1	át	FÉRJ
26	át	1	FÉRJ	hez
27	FÉRJ	1	hez	AD
28	hez	1	AD	ni
29	AD	1	ni	STOP
30	STOP	1	ez	nem
31	ez	1	nem	is
32	nem	1	is	lett
33	is	1	lett	VOL
34	na	1	NE	héz
35	NE	1	héz	mert
36	héz	1	mert	HÁ
37	egy, rom	2	OR	2-szág
38	2-OR	2	szág	STOP, a
39	ány	1	á	ra
40	á	1	ra	JUT
41	ra	1	JUT	ott
42	JUT	1	ott	EDY

We have to add to **Table 3** the bonds and classes generated in the previous step:

W1	{az, egy}-Ö	W2	{a,s}-HÁ
W3	rom-{LE, szép}	W4	ány-{ a, át }
W5	{mind, ány}-a		
W6	rom-{LE, szép} $\Rightarrow$ rom-{ LE-ány, szép}		
W7	{mind, ány}-a $\Rightarrow$ {mind, LE-ány}-a		
$\{\ddot{O}, \text{reg}\} \Leftrightarrow \ddot{O}\text{-reg}$; $\{\text{reg}, \text{KI}\} \Leftrightarrow \text{reg-KI}$; $\{\text{KI} + \text{rally}\} \Leftrightarrow \text{KI-rally}$; $\{\ddot{O}, \text{reg}, \text{KI}, \text{rally}\} \Leftrightarrow \ddot{O}\text{-reg-KI-rally}$; $\{\text{LE}, \text{ány}\} \Leftrightarrow \text{LE-ány}$;			

The new material in **Table 3** is highlighted yellow. New bonds and classes can be extracted from the following lines, which can be characterized as **relevant novelty**:

6	az, egy	2	Ö	2-reg
---	---------	---	---	-------

12	2-a, mert, s	4	HÁ	4-rom
13	4-HÁ	4	rom	2-LE, OR, szép

17	2-mind, szág, ány	4	a	2-HÁ, STOP, volt
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22	lett, te	2	VOL	2-na
23	2-VOL	2	na	NE, mind

37	egy, rom	2	OR	2-szág
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New bonds:

$\{\text{VOL-na}\} \Leftrightarrow \text{VOL-na}$

$\{\text{OR}, \text{szág}\} \Leftrightarrow \text{OR-szág}$

Expansion of old classes:

W1 {a, mert, s }-HÁ

W3 rom-{LE, szép, OR}

W5 {mind, ány, szág}-a

New classes:

W8 {az, egy}-Ö

W9 a-{ HÁ, volt}

W10 {lett, te}-VOL

W11 na-{NE, mind}

Some of new equilibriums:

{mind} $\Leftrightarrow$ mind-a-HÁ-rom-LE-ány (“all three girls”)

{ HÁ } $\Leftrightarrow$ HÁ-rom-OR-szág

{KI-rály} $\Leftrightarrow$ az-Ö-reg-KI-rály

I intentionally do not interpret the classes, but a linguist even very superficially familiar with Hungarian will note that **egy** and **az** in W8 make up for two out of three Hungarian forms of the article (**egy**, **a**, and **az**) . In the subsequent text, **KI-rály** will bind all articles in a class and, therefore, all nouns and adjectives will be bound in class by the articles. This creeping and crawling process of triangulation, which in the eyes of a chemist is nothing but catalysis, seems to be the essence of language acquisition and growth in general. I would compare it with a group of mountain climbers who help and safeguard each other.

I will illustrate the main idea of the “chemical” approach to language acquisition from a slightly different angle, with relation to [7]. I repeat **Table 2** with additional columns that indicate only bonds and classes of syllables. Thus, generator **Ö**, (1) forms a bond with **-reg** on the right and (2) denotes a class including **az** and **egy** on the left. Generator **ány** (1) forms a bond with **LE** on the left and (2) denotes a class including **a** and **s** on the right. Since we are in the very beginning of acquisition, the three last columns do not contain any new information, but with next steps the new and more general classes, for example, what we call Article of Noun, can be added.

Table 2A

	LEFT		G	RIGHT	BOND	Class UP	Class DOWN
1	a	3	STOP	az			
2	STOP	1	volt	EDY			
3	volt	1	EDY	szer			
4	EDY	1	szer	egy			
5	szer	1	egy	Ö			
6	az, egy	2	Ö	2-reg	-reg	{az-, egy-}	
7	2-Ö	2	reg	2-KI			
8	2-reg	2	KI	2-rály	-rály		
9	2-KI	2	rály	PAUSE, SZE	KI-		
10	rály	1	PAUSE	s			
11	PAUSE	1	s	HÁ			
12	a, s	2	HÁ	2-rom	-rom	{a-, s-}	
13	2-HÁ	2	rom	LE, szép	HÁ-		{-LE, -szép}
14	rom	1	szép	LE			
15	rom, szép	2	LE	2-ány		{rom-, szép-}	
16	2-LE	2	ány	a, át			{-a, -át}
17	mind, ány	2	a	HÁ, STOP		{mind-, ány-}	
18	STOP	1	az	Ö			
19	rály	1	SZE	ret			
20	SZE	1	ret	te			
21	ret	1	te	VOL			
22	te	1	VOL	na			
23	VOL	1	na	mind			
24	na	1	mind	a			
25	ány	1	át	FÉRJ			
26	át	1	FÉRJ	hez			
27	FÉRJ	1	hez	AD			

28	hez	1	AD	ni			
29	AD	1	ni	STOP			

Let us consider all possible arrangements of three generators: **a**, **HÁ**, and rom.

1. **a-HÁ-rom**
2. a-rom-HÁ
3. **HÁ-rom-a**
4. **HÁ-rom-a**
5. rom-a-HÁ
6. rom-HÁ-a

Only triplet **a-HÁ-rom** contains **both** regular bond **HÁ-rom** and the regular class **a-HÁ**. Therefore, the transition state from thought to utterance that contains this triplet has the lowest energy among six triplets and the utterance that includes it has the highest chance to be generated at normal conditions.

Along the same principles, it follows from **Table 2A** (but not from the final state of language knowledge) that **Fragment 1** below has better chances than **Fragment 2**. In both fragments, **HÁ-rom** (“three”) and **LE-ány** (“girl”) are considered relatively stable generators.

Fragment 1: [a]—[HÁ-rom]—[LE-ány]. **Fragment 2:** [LE-ány]—[a]—[HÁ-rom].

I balk at the next steps of acquisition before the process becomes too cumbersome, but here is the table for the next step:

Step 4

P4 = char ('HA', 'nem', 'A', 'hogy', 'an', 'nincs', 'HÁ', 'rom', 'EDY', 'for', 'ma', 'AL', 'ma',
'PAUSE', 'ügy', 'a', 'HÁ', 'rom', 'OR', 'szág', 'sem', 'voltage', 'EDY', 'for', 'ma', 'STOP');
P=strvcat (P2, P3, P4, P5);

Table 4

1	a, ni, szág	5	STOP	HA, az, ez
2	STOP, a, sem	3	volt	2-EDY, PAUSE
3	ott, rom, 2-volt	4	EDY	egy, 2-for, szer
4	EDY	1	szer	egy
5	EDY, szer	2	egy	OR, Ö
6	az, egy	2	Ö	2-reg
7	2-Ö	2	reg	2-KI
8	2-reg	2	KI	2-rály

9	2-KI	2	rály	PAUSE, SZE
10	ma, rály, volt	3	PAUSE	mind, s, úgy
11	PAUSE	1	s	HÁ
12	3-a, mert, nincs, s	6	HÁ	6-rom
13	6-HÁ	6	rom	EDY, 2-LE, 2-OR, szép
14	rom	1	szép	LE
15	2-rom, szép	3	LE	3-ány
16	3-LE	3	ány	a, á, át
17	2-mind, szág, ány, úgy	5	a	3-HÁ, STOP, volt
18	STOP	1	az	Ö
19	rály	1	SZE	ret
20	SZE	1	ret	te
21	ret	1	te	VOL
22	lett, te	2	VOL	2-na
23	2-VOL	2	na	NE, mind
24	PAUSE, na	2	mind	2-a
25	ány	1	át	FÉRJ
26	át	1	FÉRJ	hez
27	FÉRJ	1	hez	AD
28	hez	1	AD	ni
29	AD	1	ni	STOP
30	STOP	1	ez	nem
31	HA, ez	2	nem	A, is
32	nem	1	is	lett
33	is	1	lett	VOL
34	na	1	NE	héz
35	NE	1	héz	mert
36	héz	1	mert	HÁ
37	egy, 2-rom	3	OR	3-szág
38	3-OR	3	szág	STOP, a, sem
39	ány	1	á	ra
40	á	1	ra	JUT
41	ra	1	JUT	ott
42	JUT	1	ott	EDY
43	STOP	1	HA	nem
44	nem	1	A	hogy
45	A	1	hogy	an
46	hogy	1	an	nincs
47	an	1	nincs	HÁ
48	2-EDY	2	for	2-ma
49	AL, 2-for	3	ma	AL, PAUSE, STOP
50	ma	1	AL	ma
51	PAUSE	1	úgy	a
52	a	1	sem	volt

We can use a bigger or even complete text if we unrealistically assume that it all can be kept in the focus of attention (called **window** in psycholinguistics). This is impossible with real children but possible with robot-child. One practical implementation of language chemistry can be the actual simulation of robot-child and its learning. Like the wheel, it may be unnatural, but practical.

I emphasize that the entire concept is no more than a hypothesis and it needs a lot of further confirmations of its validity, which could be my next task.

The essence is, in very general terms, that the child creates its own grammar which is constantly and significantly updated by the input in an incremental manner. In other words, grammar is a kind of a biological species, very primitive in the beginning, which evolves in the environment of input and an exchange with environment into its final complex form which remains individual. The mechanism of this evolution consists of simplistic and somewhat mechanical rules. In this sense, the child possesses a real Language Acquisition **Device**, as Chomsky prophetically called it, which works until the active learning takes off. The LAD quite mechanically (i.e., “chemically”) generates hypotheses about the grammar (i.e., regularity of PT) for further tests.

Thus, at the initial stage, if the entire input is nothing but a single tale about salt, the child-robot, probably, knows that **HÁ-rom** (“three”) is a separate word because it occurs in different environments, but perceives **Ö-reg-KI-rály** (“old king”) as a single word because there is no evidence to the contrary.

The complete text [4], translation, and its complete **Table 4** are given in the **APPENDIX** for those who would like to see for themselves how much grammar can be extracted from the triplets. Obviously, not all of it, but quite a lot, which will be enough for telling simple tales in a simple language.

Next I will select some lines from **Table 4** and expand them, as before, with columns **Bond (B)**, **Class UP (CUP)**, **Class Down (CDN)**, and **New G(NG)**, filled out manually in order to provide more illustrations. This time I will give some translations.

	LEFT		G	RIGHT	Bond	CUP	CDN	NG
2	STOP, a, ez, kos, lan, len, meg, nem, sem, szép	10	volt	AZ, 2-EDY, KÜ, PAUSE, STOP, TER, a, csak, mind	volt- EGY			

Line 2. Since **volt-EGY** occurs more than once, formally, there is a bond between them. This is a hypothesis the child-robot’s LAD has to make.

	LEFT		G	RIGHT	Bond	CUP	CDN	NG
3	STOP, ig, még, ott, rom, ta, 2-volt	8	EDY	egy, et, 2-for, ma, 3-szer	EDY-for-ma, EDY-szer			
49	AL, EDY, Még, 2-for	5	ma	AL, PAUSE, STOP, gá, is	forma			

Line 3. Since there is a hypothetical bond **EGY-szer** (“once”) , **Lines 2 and 3** imply a block **volt-EGY-szer**. This hypothesis could be further rejected, but in the context of the tale it is justified: “there was once...” is a standard beginning of a folk tale.

Similarly, **Lines 3 and 49** imply **EDY-for-ma** (“equal,” “same”) ,as a block, and this hypothesis is correct. Other examples of **bond** formation can be seen in **Table 4**. **No** in **Line 223** is an interjection, naturally, between two pauses.

	LEFT		G	RIGHT	Bond	Class Up	Class Down	NG
53	2-PAUSE, STOP, szer, 2-én	6	azt	FEL, HAL, 3-MOND, ROS	aztMONDta			
54	3-PAUSE, STOP, 3-azt	7	MOND	jad, 5-ta, tam	MONDta			
55	HAGY, JÁR, 5-MOND, TISZ, TUD, ad, dol, fog, 2-lát, nál, tol, áz	17	ta	BÚZ, EDY, MA, MEG, SZOM, 7-a, az, hogy, lak, már, szó		V-ta (V= verb)		
80	Azt, 3-PAUSE, ged, nem	6	KÉR	6-dez	KÉRdez			
81	6-KÉR	6	dez	lek, 4-te, tem	KÉRdezte			
86	a, két	2	GA	2-lamb	GAlamb			
180	2-MEG	2	lát	2-ta	MEGlátta			
223	3-STOP	3	No	3-PAUSE	PAUSE-No-PAUSE			

Some of the bonds will survive, other will not. The grammar that the child-robot builds looks like a kind of a living evolving ecosystem rather than an artificial zoo of species.

	LEFT		G	RIGHT	Bond	Class Up	Class Down	NG
17	STOP, 2-ban, de, 2-dult, 2-ek, 2-em, ett, i, ik, ja, járt, jött, lamb, ment, 2-mind, mint, nak, rá, 2-rály, rályt, szer, szett, szág, sírt, 7-ta, 6-te, ták, ték, volt, 3-ány, úgy	50	a	2-FI, GA, 3-HÁ, KAN, KEZ, 12-KI, KÖ Z, 6-LE, 4-LEG, 2-PA, PE, PIL, RU, 2-STOP, SZEL, TISZ, TÖB, VA, i, 6-sót, volt	a-XYZ...		-XYZ	
21	TET, 4-dez, el, 2-et, get, hát, ret, szélsz	12	te	MIND, 2-PAUSE, STOP, TOL, VOL, 6-a	KÉRdezte-a...	...xyz-te		

Line 17. Hungarian **a /az** is the definite article. It is, as the mathematicians say, “degenerated” by having too many possible neighbors. Its function seems vague. But while most of the neighbors on the right are stressed (capitalized) syllables, i.e., beginnings of words, those on the left are, remarkably, all unstressed.

NOTE: **sót** is the objective case of **só**, “salt.” I did not capitalized it because of the inconsistency of my hyphenation rules, but it is a noun.

The hypothesis is that there is a bond between article **a** and any stressed syllable denoted as XYZ. It also follows that the definite article forms a Class Down, i.e., a class of all words that follow it. A linguist would call it the class of nouns, but the child does not know linguistics. In the beginning of acquisition, morpheme **i** and verb **volt** (“was”) seems to be included in the class erroneously. This is because morpheme **a** is not only an article but also a multi-functional marker for verbs and nouns. The vocabulary of the tale is not sufficient to make some correct grammatical assignments. Other examples with **XYZ** or unstressed **xyz** can also be found in the **Table**.

Line	LEFT		G	RIGHT	Bond	Class Up	Class Down	New G
18	PAUSE, STOP, ban, csak, el, en, 2-hogy, ki, mert, mint, még, ra, rály, sót, ta, ve, ílt, irt, ült	20	az	AJ, AP, AR, ASZ, EB, 3-EM, OR, UD, ÉD, ÉT, 8-Ö	az-XYZ... X=vowel; azÖreg...		-XYZ	

60	PAUSE, 4-a, rály	6	LEG	i, job, 2-kis, nagy, szebb	a LEG kis?			
117	5-kis	5	asz	4-szony, szonyt				-t
220	et, het, tet	3	ték	EGY, PAUSE, a		xyz-t-ték		-t
95	az, 3-es	4	AP	2-ád, 2-ám	APád, APám		AP-{ád, ám}	
96	2-AP, BÁTÝ	3	ám	2-PAUSE, UR		XYZ-ám		

Line 18. Definite article **a** takes the form **az** before vowels. Due to the limitation of the current vocabulary, a hypotheses about the block **az-Ö-reg-KI-rály** (“the old king”) is formed, which is true only within the context of this tale, together with the correct bond **az-XYZ...** , where **X** = vowel.

At the same time, the article **a/az** creates a large class of syllables belonging to what we call nouns, numerals, and adjectives, so that the acquisition device rather early marks the category of nouns and adjectives.

Line 60. **LEG** (Superlative morpheme) forms bonds with **kis** (“little, small”), which, in turn, can be extended to either **asz** (**assz**) , bonded further with **szony** or **ebb**.

Therefore, **kis** can be a component of either block **LEG-kis-ebb** , “the youngest” or block **KI-rály-kis-asz-szony** , “princess” (literally, king-little-lady). How can the child-robot decide which? It depends on what other components are there in the focus. In the tale, the choice is unambiguous because **ebb** and **asszony** are not encountered between two stops.

Line 95. **AP-ád** , (“your father”) an **AP-ám** (“my father”) create a class **-{ -ád, -ám}** , which itself creates class **XYZ-{ -ád, -ám}** if more **XYZ** with **ád** and/or **ám** are encountered. This nouns and possessive endings are thereby bonded as two classes.

Line 117. The fact that **asszony** (“woman, lady”) and **asszonyt** (Object Case) differ in a sound implies that **t** can be a generator, although it is not a syllable. And in fact, **t** is an important multifunctional marker in Hungarian. See also **Line 220** .

Those are some of many bits of grammar that the robot-child can acquire from the *Tale of Salt*.

As I hinted in previous e-papers [1], the language acquisition is just one case of the entire class of processes of growth. Knowledge acquisition, for example, by scientific means, is another one. The child-robot works by building and updating hypotheses, as the scientist does. Biological mutations are hypotheses of a kind, too. Both biological and language-acquisition mutations do not involve any mind.

I assume that the pattern model of the mind can be built **incrementally**, along the principles of **simplicity** [1], in the same way a child acquires language or builds a Lego palace, i.e., with almost no thinking involved. When some intermediate construct seems unstable (contradictive or counterproductive, i.e. working against homeostasis), an improvement is made by trial and error. Whatever I have presented regarding language, however, does not take to account homeostasis. The actual building of the model of the mind will naturally include it.

In general, three general ideas, none of them new, seem to emit guiding light:

1. Language acquisition is a counterpart of biological evolution of species and natural evolution of knowledge.
2. Language acquisition device (LAD) is really a device, which, like any device, works as a mechanism, even though somewhat lax and wobbly.
3. Language acquisition is like packing a parachute: if some sections do not go first, and other last, it will not open. This is the essence of bootstrapping.

Further work with ***Salt*** and other objects

It is obvious that my manual analysis of triplet tables is subjective and cumbersome. A computer code for incremental simplistic learning from syllabic input is needed. Can the code itself be simple? How far can we go with simplicity? Do we need forgetting in order

to learn? Etc. Ultimately, can we construct an interface between thought and speech, working on principles of kinetics? A next step in my program is to explore the transition state. The question is: how can a semantic configuration be squashed into the line with the help of a triplet grammar? As a chemist, I clearly see the whole mechanism, but to present it to non-chemists as a model is a challenge.

Questions, suggestions and shattering criticism are welcome at:

EMAIL: <http://spirospero.net/email.html>

References

See also <http://spirospero.net/complexity.htm>

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APPENDIX

The approximate pronunciation of some consonants is: **gy** = **d** in “due”, **j** and **ly** = **y** in “you,” **s** = **sh**, **sz** = **s**, and **cs** = **ch**. The short vowels are: **a**, **e**, **i**, **o**, **u**, **ö**, and **ü**; they all sound, approximately, as in German. The long vowels are **Á á**, **É é**, **Í í**, **Ó ó**, **Ú ú**, and **Ő ő**. The latter, **Ő ő**, which is not rendered by MATLAB, will be alternatively denoted **Õ õ**. The stress and the length of the vowels are independent, which gives the Hungarian language its characteristic syncopated melody. The stress is on the first syllable, but what is a syllable? I don’t hear it as carved in stone.

A SÓ

The transcription of the folktale by Elek Benedek [5] .

Volt egyszer egy öreg király s három szép leánya. Az öreg király szerette volna mind a három leányát férjhez adni. Ez nem is lett volna nehéz, mert három országa volt, mind a három leányára jutott egy-egy ország. Hanem ahogyan nincs három egyforma alma, úgy a három ország sem volt egyforma.

Azt mondta egyszer a király a leányainak, hogyannak adja a legszebb országát, amelyik őt legjobban szereti.

- Felelj nekem, édes leányom, hogy szeretsz engem? - kérdezte a legidősebbiket.
 - Mint a galamb a tiszta búzát - mondta a leány.
 - Hát te, édes leányom? - kérdezte a középsőt.
 - Én úgy, édesapám, mint forró nyárban a szellőt.
 - No, most téged kérdezlek - fordult a legkisebbikhez -, mondjad, hogy szeretsz?
 - Úgy, édesapám, ahogy az emberek a sót! - felelte a kicsi királykisasszony.
 - Mit beszélsz, te! - förmedt rá a király. – Ki az udvaromból, de még az országomból is!
- Ne is lássalak, ha csak ennyire szeretsz!

Hiába sírt a királykisasszony, hiába magyarázta, hogy az emberek szeretik a sót: világga kellett hogy menjen.

Elindult a kicsi királykisasszony sírva, s beért egy nagy erdőbe. Onnan nem is ment tovább, ott élt egy darabig egymagában.

Egyszer, mikor már egy esztendő is eltelt, arra járta szomszéd királyfi, s meglátta a királykisasszonyt.

Megtetszett a királyfinak a királykisasszony, mert akármilyen piszkos volt a ruhája, szép volt, különösen az arca. Szépen megfogta a kezét, hazavezette a palotájába, s két hetet sem várt, de még egyet sem, de talán még egy órát sem, és megesküdték.

A fiatal pár békésen élt, úgy szerették egymást, mint két galamb. Egyszer azt mondta a király:

- No, feleség, amikor először megláttalak, nem kérdeztem, miért kergetett el az apád.

Mondd meg nekem a valóságot!

- Azt kérdezte tőlem, hogy szeretem őt, s én azt feleltem: mint az emberek a sót.

- Jól van, majd csinállok én valamit, tudom, megszeret újra az édesapád - mondta a király.

S azzal levelet írt az öreg királynak, s abban meghívta ebédre. El is ment a levél másnap, s harmadnap jött a király. Fölvezette a fiatal király az öreg királyt a palotába. Ott már meg volt terítve az asztal két személyre s leültek. No, ez volt csak az ebéd! Megkóstolta az öreg király a levest, de le is tette mindjárt a kanalat, nem tudta megenni, olyan sótlan volt. Gondolta magában az öreg király: ebből bizony kifelejtették a sót, de a többi ételben majd csak lesz. De nem volt azokban sem. Hordták a pecsenyéket, de vissza is vihették, mert az öreg király bele sem harapott, olyan sótlan, ízetlen volt mind. De ezt már nem hagyta szó nélkül:

- Hallod-e, öcsém, hát milyen szakácsod van neked, hogy só nélkül süt-főz? - kérdezte.

- Sóval süt-főz ez máskor mindig, de én azt hallottam, hogy bátyámuram nem szereti a sót, azt mondtam hát neki, hogy ne tegyen sót az ételekbe.

- No, azt rosszul tetted, mert én nagyon szeretem a sót. Kitől hallottad, hogy nem szeretem?

- A leányától - mondta a fiatal király. Abban a pillanatban kinyílt az ajtó, és belépett a királyné, az öreg király legkisebb leánya. Hej, istenem, örült az öreg király! Mert sajnálta már nagyon, hogy elkergette a leányát. Most neki adta a legnagyobb országát. Még ma is élnek, ha meg nem haltak.

Translation:

Salt

Once upon a time there lived an old king with his three beautiful daughters. The old king wanted all three his daughters to get married. It would not be difficult because he had three lands, one for each daughter. But as there are no three apples alike, so there are no three lands alike. And so the king told his daughters that he will give the best kingdom to the daughter who loves him most.

“Tell me, my dear daughter, how do you love me?” he asked the oldest.

“As a dove loves pure grain,” answered the eldest.

“And you, dear daughter?” He asked the middle one.

“And I love you as much as a breeze in hot summer.”

“Now I am asking you, he turned to the youngest, tell me how do you love me?”

“As much, dear father, as people love salt,” answered the little princess.

“What are you saying!” The king shouted. “Off my court, and get out of my land. I don’t want to see you if you love me that much.”

In vain the princess cried, in vain explained how people like salt: she had to go. The little princess left in tears and came to a big forest. She did not go any further, she lived there completely on her own.

Once , when already a year had passed, a neighboring prince came there and saw the little princess. The prince was struck by the princess because however shabby her dress was, she was beautiful, especially, her face. He gently took her hand and brought her to his palace, and not in two weeks, not even one, maybe not even in an hour they got married.

The young couple lived in love like two doves.

One day the king said, “Well, my wife, when I first saw you, I did not ask why your father banished you. Tell me the truth!”

“He had asked me how I loved him and I answered: as people love salt.”

“Good, then I know how to do something so that you father will love you again,” said the king. And he wrote a letter, inviting the old king for dinner. Next day the letter went out and after another day the king arrived. The young king invited the old king into his palace. There already was a table set for two and they sat down. But what a dinner it was! The old king tried the soup but had to put down the spoon at once and could not eat because it was without salt. The old king thought for himself: here certainly the salt was forgotten, but probably not in other food. But there was no salt either. The roast was brought in but taken back because the old king could not take a bite, so saltless and tasteless everything was. But he already lost his patience.

“Listen, young man, what kind of cook do you have that cooks without salt?” He asked.

“He always cooks with salt in other times but I heard that you, sir, do not like salt, so I said to him not to salt food.”

“Well, this is very bad that you did so because I like salt very much. From whom did you hear that I do not like it?”

“From your daughter,” said the young king.

At this moment, the door opened and the queen, the youngest daughter of the old king, entered. Good Lord, how the old king rejoiced! Now he regretted very much having chased the girl away. Now he gave her the largest land.

They are still living, if have not died.

Input string for MATLAB

```
P=char ('STOP','volt','EDY','szer','egy','Ö','reg','KI','rály','PAUSE','s','HÁ', ...
'rom','szép','LE','ány','a','STOP','az','Ö','reg','KI','rály', ...
'SZE','ret','te','VOL','na','mind','a','HÁ','rom','LE','ány','át','FÉRJ','hez', ...
'AD','ni','STOP','ez','nem','is','lett','VOL','na','NE','héz','mert','HÁ', ...
'rom','OR','szág','a','volt','PAUSE','mind','a','HÁ','rom','LE', ...
'ány','á','ra','JUT','ott','EDY','egy','OR','szág','STOP','HA','nem','A', ...
'hogy','an','nincs','HÁ','rom','EDY','for','ma','AL','ma','PAUSE','úgy','a', ...
'HÁ','rom','OR','szág','sem','volt','EDY','for','ma','STOP', ...
'azt','MOND','ta','EDY','szer','a','KI','rály','a','LE','ány','a','i','nak', ...
'hogy','AN','nak','AD','ja','a','LEG','szebb','OR','szág','át','PAUSE','A', ...
'mely','ik','öt','PAUSE','LEG','job','ban','SZER','e','ti','STOP','FEL','elj', ...
```


'NEK', 'em', 'PAUSE', 'ÉD', 'es', 'LE', 'ány', 'om', 'PAUSE', 'hogy', 'SZER', 'etsz', ...
 'EN', 'gem', 'PAUSE', 'KÉR', 'dez', 'te', 'a', 'LEG', 'i', 'dő', 'sebb', 'ik', 'et', ...
 'STOP', 'mint', 'a', 'GA', 'lamb', 'a', 'TISZ', 'ta', 'BÚZ', 'át', 'PAUSE', 'MOND', ...
 'ta', 'a', 'LE', 'ány', 'STOP', 'hát', 'te', 'PAUSE', 'ÉD', 'es', 'LE', 'ány', 'om', 'PAUSE', ...
 'KÉR', 'dez', 'te', 'a', 'KÖZ', 'ép', 'sőt', 'STOP', 'én', 'ügy', 'ÉD', 'es', 'AP', ...
 'ám', 'PAUSE', 'mint', 'FOR', 'ró', 'NYÁR', 'ban', 'a', 'SZEL', 'lőt', 'STOP', 'no', ...
 'most', 'TÉ', 'ged', 'KÉR', 'dez', 'lek', 'PAUSE', 'FOR', 'dult', 'a', 'LEG', 'kis', 'ebb', ...
 'ik', 'hez', 'STOP', 'MOND', 'jad', 'hogy', 'SZER', 'etsz', 'STOP', 'ügy', 'ÉD', ...
 'es', 'AP', 'ám', 'PAUSE', 'A', 'hogy', 'az', 'EM', 'ber', 'ek', 'a', 'sót', 'PAUSE', 'FEL', ...
 'el', 'te', 'a', 'KI', 'csi', 'KI', 'rály', 'kis', 'asz', 'szony', 'STOP', 'mit', 'BE', ...
 'szélsz', 'te', 'PAUSE', 'FÖR', 'medt', 'rá', 'a', 'KI', 'rály', 'STOP', 'ki', 'az', ...
 'UD', 'var', 'om', 'ból', 'de', 'még', 'az', 'OR', 'szág', 'om', 'ból', 'is', 'PAUSE', ...
 'STOP', 'ne', 'IS', 'lás', 'sa', 'lak', 'PAUSE', 'ha', 'csak', 'EN', 'nyi', 're', 'SZER', ...
 'etsz', 'STOP', 'HI', 'á', 'ba', 'sír', 'a', 'KI', 'rály', 'kis', 'asz', 'szony', 'PAUSE', ...
 'HI', 'á', 'ba', 'MA', 'gyar', 'áz', 'ta', 'hogy', 'az', 'EM', 'ber', 'ek', 'SZER', ...
 'et', 'ik', 'a', 'sót', 'PAUSE', 'VI', 'lág', 'gá', 'KEL', 'lett', 'hogy', 'MENJ', 'en', ...
 'STOP', 'EL', 'in', 'dult', 'a', 'KI', 'csi', 'KI', 'rály', 'kis', 'asz', 'szony', 'SÍR', ...
 'va', 'PAUSE', 's', 'BE', 'ért', 'egy', 'nagy', 'ER', 'dő', 'be', 'STOP', 'ON', ...
 'nan', 'nem', 'is', 'ment', 'TO', 'vább', 'PAUSE', 'ott', 'élt', 'egy', 'DA', 'rab', 'ig', ...
 'EDY', 'ma', 'gá', 'ban', 'STOP', 'EDY', 'szer', 'MI', 'kor', 'már', 'egy', ...
 'ESZT', 'en', 'dő', 'is', 'el', 'telt', 'PAUSE', 'ar', 'ra', 'JÁR', 'ta', 'SZOM', 'széd', ...
 'KI', 'rály', 'fi', 'PAUSE', 's', 'MEG', 'lát', 'ta', 'a', 'KI', 'rály', 'kis', 'asz', 'szonyt', ...
 'STOP', 'MEG', 'tet', 'szett', 'a', 'KI', 'rály', 'fi', 'nak', 'a', 'KI', 'rály', ...
 'kis', 'asz', 'szony', 'PAUSE', 'mert', 'A', 'kár', 'mi', 'lyen', 'PISZ', 'kos', ...
 'volt', 'a', 'RU', 'há', 'ja', 'PAUSE', 'szép', 'volt', 'KÜ', 'lön', 'ös', 'en', 'az', 'AR', ...
 'ca', 'STOP', 'SZÉP', 'en', 'MEG', 'fog', 'ta', 'a', 'KEZ', 'ét', 'PAUSE', ...
 'HA', 'za', 'vez', 'et', 'te', 'a', 'PA', 'lot', 'á', 'já', 'ba', 'PAUSE', 's', 'két', 'HET', ...
 'et', 'sem', 'várt', 'PAUSE', 'de', 'még', 'EDY', 'et', 'sem', 'de', 'TAL', ...
 'án', 'még', 'egy', 'ÓR', 'át', 'sem', 'PAUSE', 'és', 'MEG', 'es', 'küd', 'tek', 'STOP', ...
 'A', 'FI', 'at', 'al', 'pár', 'BÉ', 'kés', 'en', 'élt', 'PAUSE', 'ügy', 'SZER', 'et', 'ték', ...
 'EGY', 'mást', 'PAUSE', 'mint', 'két', 'GA', 'lamb', 'STOP', 'EGY', 'szer', 'azt', 'MOND', ...
 'ta', 'a', 'KI', 'rály', 'STOP', 'No', 'PAUSE', 'FE', 'le', 'ség', 'PAUSE', 'A', 'mi', 'kor', 'EL', ...
 'o', 'ször', 'MEG', 'lát', 'ta', 'lak', 'PAUSE', 'nem', 'KÉR', 'dez', 'tem', 'PAUSE', 'MI', ...
 'ért', 'KER', 'get', 'ett', 'el', 'az', 'AP', 'ád', 'STOP', 'MONDD', 'meg', 'NEK', 'em', 'a', 'VA', ...
 'ló', 'ság', 'ot', 'STOP', 'Azt', 'KÉR', 'dez', 'te', 'TOL', 'em', 'PAUSE', 'hogy', 'SZER', ...
 'et', 'em', 'ot', 'PAUSE', 's', 'én', 'azt', 'FEL', 'el', 'tem', 'PAUSE', 'mint', 'az', 'EM', 'ber', ...
 'ek', 'a', 'sót', 'STOP', 'Jól', 'van', 'PAUSE', 'majd', 'CSI', 'nál', 'ok', 'én', 'VA', 'la', 'mit', ...
 'PAUSE', 'TUD', 'om', 'PAUSE', 'MEG', 'szeret', 'ÚJ', 'ra', 'az', 'ÉD', 'es', 'AP', 'ád', ...
 'PAUSE', 'MOND', 'ta', 'a', 'KI', 'rály', 'STOP', 's', 'AZ', 'zal', 'LE', 'vel', 'et', 'írt', 'az', ...
 'Ö', 'reg', 'KI', 'rály', 'nak', 'PAUSE', 's', 'AB', 'ban', 'MEG', 'hívta', 'EB', 'éd', 're', ...
 'STOP', 'EI', 'is', 'ment', 'a', 'LE', 'vé', 'MÁS', 'nap', 'PAUSE', 's', 'HAR', 'mad', 'nap', ...
 'jött', 'a', 'KI', 'rály', 'STOP', 'FÖL', 'vez', 'et', 'te', 'a', 'FI', 'at', 'al', 'KI', 'rály', 'az', 'Ö', ...
 'reg', 'KI', 'rály', 'a', 'PA', 'lo', 'tá', 'ba', 'STOP', 'Ott', 'már', 'meg', 'volt', 'TER', 'ít', 've', ...
 'az', 'ASZ', 'tal', 'két', 'SZEM', 'ély', 're', 's', 'LE', 'ül', 'tek', 'STOP', 'No', 'PAUSE', 'ez', ...
 'volt', 'csak', 'az', 'EB', 'éd', 'STOP', 'MEG', 'kós', 'tol', 'ta', 'az', 'Ö', 'reg', 'KI', 'rály', 'a', ...
 'LE', 'vest', 'PAUSE', 'de', 'le', 'is', 'TET', 'te', 'MIND', 'járt', 'a', 'KAN', 'al', 'at', 'PAUSE', ...
 'nem', 'TUD', 'ta', 'MEG', 'en', 'ni', 'PAUSE', 'OLY', 'an', 'SÓT', 'lan', 'volt', 'STOP', ...
 'GON', 'dol', 'ta', 'MA', 'gá', 'ban', 'az', 'Ö', 'reg', 'KI', 'rály', 'STOP', 'EB', 'bol', 'BI', ...
 'zony', 'KI', 'fel', 'ej', 'tet', 'ték', 'a', 'sót', 'PAUSE', 'de', 'a', 'TÖB', 'bi', 'ÉT', 'el', 'ben', ...
 'majd', 'csak', 'lesz', 'STOP', 'De', 'nem', 'volt', 'AZ', 'ok', 'ban', 'sem', 'STOP', 'HORD', ...
 'ták', 'a', 'PE', 'cseny', 'ék', 'et', 'PAUSE', 'de', 'VIS', 'sza', 'is', 'VI', 'het', 'ték', ...
 'PAUSE', 'mert', 'az', 'Ö', 'reg', 'KI', 'rály', 'BE', 'le', 'sem', 'HA', 'rap', 'ott', 'PAUSE', ...
 'OLY', 'an', 'SÓT', 'lan', 'PAUSE', 'ÍZ', 'et', 'len', 'volt', 'mind', 'STOP', 'De', 'ezt', 'már', ...
 'nem', 'HAGY', 'ta', 'szó', 'NÉL', 'kül', 'STOP', 'HAL', 'lod', 'e', 'PAUSE', 'ÖCS', 'ém', ...
 'PAUSE', 'hát', 'MILY', 'en', 'SZA', 'kács', 'od', 'van', 'NEK', 'ed', 'PAUSE', 'hogy', 'só', ...
 'NÉL', 'kül', 'SÜT', 'foz', 'PAUSE', 'KÉR', 'dez', 'te', 'STOP', 'SÓ', 'val', 'SÜT', 'foz', ...

'ez','MÁS','kor','MIND','ig','PAUSE','de','én','azt','HAL','lot','tam','PAUSE', ...
'hogy','BÁTY','ám','UR','am','nem','SZER','et','i','a','sót','PAUSE','azt','MOND', ...
'tam','hát','NEK','i','PAUSE','hogy','ne','TEGY','en','sót','az','ÉT','el','ek','be', ...
'STOP','No','PAUSE','azt','ROS','szul','TET','ted','PAUSE','mert','én','NAGY', ...
'on','SZER','et','em','a','sót','STOP','KI','tol','HAL','lot','tad','PAUSE','hogy', ...
'nem','SZER','et','em','STOP','a','LE','ány','á','tól','PAUSE','MOND','ta','a','FI', ...
'at','al','KI','rály','STOP','AB','ban','a','PIL','la','nat','ban','KINY','ilt','az','AJ', ...
'tó','PAUSE','és','BE','lép','ett','a','KI','rály','né','PAUSE','az','Ö','reg','KI','rály', ...
'LEG','kis','ebb','LE','ány','a','STOP','Hej','PAUSE','IS','ten','em','PAUSE', ...
'ÖR','ült','az','Ö','reg','KI','rály','STOP','Mert','SAJ','nál','ta','már','NAGY','on', ...
'PAUSE','hogy','EL','ker','get','te','a','LE','ány','át','STOP','Most','NEK','i', ...
'ad','ta','a','LEG','nagy','obb','OR','szág','át','STOP','Még','ma','is','ÉL','nek', ...
'PAUSE','ha','meg','nem','HAL','tak','STOP');

Table 4: SALT complete

size (P) 1069 6 (number and length of syllables)

size (words) 1 366

No.	LEFT		G	RIGHT
1	PAUSE, STOP, 2-a, ba, ban, 2-be, ca, em, en, et, 2-etsz, hez, kül, lamb, lesz, löt, ma, mind, ni, ot, re, 7-rály, sem, szony, szonyt, szág, 2-sót, söt, te, 2-tek, ti, volt, ád, ány, 2-át, éd	50	STOP	A, AB, Azt, 2-De, EB, EDY, EGY, EL, EI, FEL, FÖL, GON, HA, HAL, HI, HORD, Hej, Jól, KI, 2-MEG, MOND, MONDD, Mert, Most, Még, 3-No, ON, Ott, STOP, SZÉP, SÓ, a, az, azt, ez, hát, ki, mint, mit, ne, no, s, én, úgy
2	STOP, a, ez, kos, lan, len, meg, nem, sem, szép	10	volt	AZ, 2-EDY, KÜ, PAUSE, STOP, TER, a, csak, mind
3	STOP, ig, még, ott, rom, ta, 2-volt	8	EDY	egy, et, 2-for, ma, 3-szer
4	3-EDY, EGY	4	szer	MI, a, azt, egy
5	EDY, már, még, szer, élt, ért	6	egy	DA, ESZT, OR, nagy, ÓR, Ö
6	8-az, egy	9	Ö	9-reg
7	9-Ö	9	reg	9-KI
8	STOP, 12-a, 2-al, 2-csi, 9-reg, széd, zony	28	KI	2-csi, fel, 23-rály, rályt, tol
9	23-KI	23	rály	BE, LEG, PAUSE, 7-STOP, SZE, 2-a, az, 2-fí, 5-kis, nak, né
10	Hej, 3-No, at, ba, e, ed, 3-em, et, fi, foz, gem, i, ig, is, ja, 2-lak, lan, lek, ma, mit, mást, nak, nap, nek, ni, né, 3-om, on, ot, ott, rály, sem, 2-szony, ség, 4-sót, tad, tam, 2-te, ted, telt, 2-tem, ték, tó, tól, va, van, vest, volt, vább, várt, ád, 2-ám, 2-át, élt, ém, ét, öt	72	PAUSE	3-A, FE, FEL, FOR, FÖR, HA, HI, IS, 3-KÉR, LEG, MEG, MI, 3-MOND, 2-OLY, STOP, TUD, VI, ar, az, 2-azt, 5-de, ez, 2-ha, 7-hogy, hát, majd, 3-mert, mind, 3-mint, 2-nem, ott, 7-s, szép, 2-ÉD, ÍZ, ÖCS, ÖR, 2-és, 2-úgy
1	7-PAUSE, STOP, re	9	s	AB, AZ, BE, HAR, HÁ, LE, MEG, két, én
2	3-a, mert, nincs, s	6	HÁ	6-rom
3	6-HÁ	6	rom	EDY, 2-LE, 2-OR, szép

4	PAUSE, rom	2	szép	LE, volt
5	6-a, ebb, 2-es, 2-rom, s, szép, zal	14	LE	vel, vest, vél, 10-ány, ül
6	10-LE	10	ány	STOP, 3-a, 2-om, 2-á, 2-át
7	STOP, 2-ban, de, 2-dult, 2-ek, 2-em, ett, i, ik, ja, járt, jött, lamb, ment, 2-mind, mint, nak, rá, 2-rály, rályt, szer, szett, szág, sirt, 7-ta, 6-te, ták, ték, volt, 3-ány, úgy	50	a	2-FI, GA, 3-HÁ, KAN, KEZ, 12-KI, KÖZ, 6-LE, 4-LEG, 2-PA, PE, PIL, RU, 2-STOP, SZEL, TISZ, TÖB, VA, i, 6-sót, volt
8	PAUSE, STOP, ban, csak, el, en, 2-hogy, ki, mert, mint, még, ra, rály, söt, ta, ve, ílt, irt, ült	20	az	AJ, AP, AR, ASZ, EB, 3-EM, OR, UD, ÉD, ÉT, 8-Ö
9	rály	1	SZE	ret
20	SZE	1	ret	te
1	TET, 4-dez, el, 2-et, get, hát, ret, szélsz	12	te	MIND, 2-PAUSE, STOP, TOL, VOL, 6-a
2	lett, te	2	VOL	2-na
3	2-VOL	2	na	NE, mind
4	PAUSE, na, volt	3	mind	STOP, 2-a
5	BÚZ, 2-szág, ÓR, 2-ány	6	át	FÉRJ, 2-PAUSE, 2-STOP, sem
6	át	1	FÉRJ	hez
7	FÉRJ, ik	2	hez	AD, STOP
8	hez, nak	2	AD	ja, ni
9	AD, en	2	ni	PAUSE, STOP
30	PAUSE, STOP, foz	3	ez	MÁS, nem, volt
1	De, HA, 2-PAUSE, am, ez, hogy, meg, már, nan	10	nem	A, HAGY, HAL, KÉR, 2-SZER, TUD, 2-is, volt
2	El, ból, dõ, le, ma, 2-nem, sza	8	is	PAUSE, TET, VI, el, lett, 2-ment, ÉL
3	KEL, is	2	lett	VOL, hogy
4	na	1	NE	héz
5	NE	1	héz	mert
6	3-PAUSE, héz	4	mert	A, HÁ, az, én
7	az, egy, obb, 2-rom, szebb	6	OR	6-szág
8	6-OR	6	szág	STOP, a, om, sem, 2-át
9	2-HI, lot, 2-ány	5	á	2-ba, já, ra, tól
40	ar, ÚJ, á	3	ra	JUT, JÁR, az
1	ra	1	JUT	ott
2	JUT, PAUSE, rap	3	ott	EDY, PAUSE, élt
3	PAUSE, STOP, sem	3	HA	nem, rap, za
4	3-PAUSE, STOP, mert, nem	6	A	FI, 2-hogy, kár, mely, mi
5	2-A, 7-PAUSE, jad, lett, nak, ta	13	hogy	AN, BÁT, EL, MENJ, 3-SZER, an, 2-az, ne, nem, só
6	2-OLY, hogy	3	an	2-SÓT, nincs
7	an	1	nincs	HÁ
8	2-EDY	2	for	2-ma
9	AL, EDY, Még, 2-for	5	ma	AL, PAUSE, STOP, gá, is
50	ma	1	AL	ma
1	2-PAUSE, STOP, én	4	úgy	SZER, a, 2-ÉD
2	ban, 2-et, le, szág, át	6	sem	HA, PAUSE, STOP, de, volt, várt
3	2-PAUSE, STOP, szer, 2-én	6	azt	FEL, HAL, 3-MOND, ROS
4	3-PAUSE, STOP, 3-azt	7	MOND	jad, 5-ta, tam
5	HAGY, JÁR, 5-MOND, TISZ, TUD, ad, dol, fog, 2-lát, nál, tol, áz	17	ta	BÚZ, EDY, MA, MEG, SZOM, 7-a, az, hogy, lak, már, szó
6	LEG, 2-NEK, a, et	5	i	PAUSE, a, ad, dõ, nak

7	AN, fi, i, rály	4	nak	AD, PAUSE, a, hogy
8	hogy	1	AN	nak
9	AD, há	2	ja	PAUSE, a
60	PAUSE, 4-a, rály	6	LEG	i, job, 2-kis, nagy, szebb
1	LEG	1	szebb	OR
2	A	1	mely	ik
3	ebb, et, mely, sebb	4	ik	a, et, hez, őt
4	ik	1	őt	PAUSE
5	LEG	1	job	ban
6	2-AB, NYÁR, 2-gá, job, nat, ok	8	ban	KINY, MEG, STOP, SZER, 2-a, az, sem
7	ban, ek, 3-hogy, 2-nem, on, re, úgy	10	SZER	e, 6-et, 3-etsz
8	SZER, lod	2	e	PAUSE, ti
9	e	1	ti	STOP
70	PAUSE, STOP, azt	3	FEL	2-el, elj
1	FEL	1	elj	NEK
2	Most, elj, hát, meg, van	5	NEK	ed, 2-em, 2-i
3	2-NEK, TOL, 3-et, ten	7	em	3-PAUSE, STOP, 2-a, ot
4	2-PAUSE, az, 2-úgy	5	ÉD	5-es
5	MEG, 5-ÉD	6	es	3-AP, 2-LE, küd
6	TUD, szág, var, 2-ány	5	om	3-PAUSE, 2-ból
7	3-SZER	3	etsz	EN, 2-STOP
8	csak, etsz	2	EN	gem, nyi
9	EN	1	gem	PAUSE
80	Azt, 3-PAUSE, ged, nem	6	KÉR	6-dez
1	6-KÉR	6	dez	lek, 4-te, tem
2	ER, en, i	3	dő	be, is, sebb
3	dő	1	sebb	ik
4	EDY, HET, 6-SZER, ik, vel, 2-vez, ÍZ, ék	14	et	PAUSE, STOP, 3-em, i, ik, len, 2-sem, 2-te, ték, irt
5	3-PAUSE, STOP	4	mint	FOR, a, az, két
6	a, két	2	GA	2-lamb
7	2-GA	2	lamb	STOP, a
8	a	1	TISZ	ta
9	ta	1	BÚZ	át
90	PAUSE, STOP, tam	3	hát	MILY, NEK, te
1	a	1	KÖZ	ép
2	KÖZ	1	ép	sőt
3	ép	1	sőt	STOP
4	STOP, de, mert, ok, s	5	én	NAGY, VA, 2-azt, úgy
5	az, 3-es	4	AP	2-ád, 2-ám
6	2-AP, BÁT	3	ám	2-PAUSE, UR
7	PAUSE, mint	2	FOR	dult, ró
8	FOR	1	ró	NYÁR
9	ró	1	NYÁR	ban
100	a	1	SZEL	lőt
1	SZEL	1	lőt	STOP
2	STOP	1	no	most
3	no	1	most	TÉ
4	most	1	TÉ	ged
5	TÉ	1	ged	KÉR
6	dez	1	lek	PAUSE
7	FOR, in	2	dult	2-a
8	2-LEG, 5-rály	7	kis	5-asz, 2-ebb

9	2-kis	2	ebb	LE, ik
110	MOND	1	jad	hogy
1	3-az	3	EM	3-ber
2	3-EM	3	ber	3-ek
3	3-ber, el	4	ek	SZER, 2-a, be
4	6-a, en	7	sót	4-PAUSE, 2-STOP, az
5	2-FEL, ett, is, 2-ÉT	6	el	az, ben, ek, te, telt, tem
6	2-KI	2	csi	2-KI
7	5-kis	5	asz	4-szony, szonyt
8	4-asz	4	szony	2-PAUSE, STOP, SÍR
9	STOP, la	2	mit	BE, PAUSE
120	mit, rály, s, és	4	BE	le, lép, szélsz, ért
1	BE	1	szélsz	te
2	PAUSE	1	FÖR	medt
3	FÖR	1	medt	rá
4	medt	1	rá	a
5	STOP	1	ki	az
6	az	1	UD	var
7	UD	1	var	om
8	2-om	2	ból	de, is
9	5-PAUSE, ból, sem	7	de	TAL, VIS, a, le, 2-még, én
130	2-de, án	3	még	EDY, az, egy
1	STOP, hogy	2	ne	IS, TEGY
2	PAUSE, ne	2	IS	lás, ten
3	IS	1	lás	sa
4	lás	1	sa	lak
5	sa, ta	2	lak	2-PAUSE
6	2-PAUSE	2	ha	csak, meg
7	ha, majd, volt	3	csak	EN, az, lesz
8	EN	1	nyi	re
9	nyi, éd, ély	3	re	STOP, SZER, s
140	PAUSE, STOP	2	HI	2-á
1	já, tá, 2-á	4	ba	MA, PAUSE, STOP, sírt
2	ba	1	sírt	a
3	ba, ta	2	MA	gyar, gá
4	MA	1	gyar	áz
5	gyar	1	áz	ta
6	PAUSE, is	2	VI	het, lát
7	VI	1	lát	gá
8	MA, lát, ma	3	gá	KEL, 2-ban
9	gá	1	KEL	lett
150	hogy	1	MENJ	en
1	ESZT, MEG, MENJ, MILY, SZÉP, TEGY, kés, ős	8	en	MEG, STOP, SZA, az, dő, ni, sőt, élt
2	STOP, hogy, kor	3	EL	in, ker, o
3	EL	1	in	dult
4	szony	1	SÍR	va
5	SÍR	1	va	PAUSE
6	BE, MI	2	ért	KER, egy
7	LEG, egy	2	nagy	ER, obb
8	nagy	1	ER	dő
9	dő, ek	2	be	2-STOP
160	STOP	1	ON	nan
1	ON	1	nan	nem

2	2-is	2	ment	TO, a
3	ment	1	TO	vább
4	TO	1	vább	PAUSE
5	en, ott	2	élt	PAUSE, egy
6	egy	1	DA	rab
7	DA	1	rab	ig
8	MIND, rab	2	ig	EDY, PAUSE
9	PAUSE, szer	2	MI	kor, ért
170	MI, MÁS, mi	3	kor	EL, MIND, már
1	Ott, ezt, kor, ta	4	már	NAGY, egy, meg, nem
2	egy	1	ESZT	en
3	el	1	telt	PAUSE
4	PAUSE	1	ar	ra
5	ra	1	JÁR	ta
6	ta	1	SZOM	széd
7	SZOM	1	széd	KI
8	2-rály	2	fi	PAUSE, nak
9	PAUSE, 2-STOP, ban, en, s, ször, ta, és	9	MEG	en, es, fog, hívta, kós, 2-lát, szeret, tet
180	2-MEG	2	lát	2-ta
1	asz	1	szonyt	STOP
2	MEG, ej	2	tet	szett, ték
3	tet	1	szett	a
4	A	1	kár	mi
5	A, kár	2	mi	kor, lyen
6	mi	1	lyen	PISZ
7	lyen	1	PISZ	kos
8	PISZ	1	kos	volt
9	a	1	RU	há
190	RU	1	há	ja
1	volt	1	KÜ	lön
2	KÜ	1	lön	ös
3	lön	1	ös	en
4	az	1	AR	ca
5	AR	1	ca	STOP
6	STOP	1	SZÉP	en
7	MEG	1	fog	ta
8	a	1	KEZ	ét
9	KEZ	1	ét	PAUSE
200	HA	1	za	vez
1	FÖL, za	2	vez	2-et
2	2-a	2	PA	lo, lot
3	2-HAL, PA	3	lot	tad, tam, á
4	á	1	já	ba
5	mint, s, tal	3	két	GA, HET, SZEM
6	két	1	HET	et
7	sem	1	várt	PAUSE
8	de	1	TAL	án
9	TAL	1	án	még
210	egy	1	ÓR	át
1	2-PAUSE	2	és	BE, MEG
2	es	1	küd	tek
3	küd, ül	2	tek	2-STOP
4	A, 2-a	3	FI	3-at

5	3-FI, al	4	at	PAUSE, 3-al
6	KAN, 3-at	4	al	2-KI, at, pár
7	al	1	pár	BÉ
8	pár	1	BÉ	kés
9	BÉ	1	kés	en
220	et, het, tet	3	ték	EGY, PAUSE, a
1	STOP, ték	2	EGY	mást, szer
2	EGY	1	mást	PAUSE
3	3-STOP	3	No	3-PAUSE
4	PAUSE	1	FE	le
5	BE, FE, de	3	le	is, sem, ség
6	le	1	ség	PAUSE
7	EL	1	o	ször
8	o	1	ször	MEG
9	dez, el	2	tem	2-PAUSE
230	ért	1	KER	get
1	KER, ker	2	get	ett, te
2	get, lép	2	ett	a, el
3	2-AP	2	ád	PAUSE, STOP
4	STOP	1	MONDD	meg
5	MONDD, ha, már	3	meg	NEK, nem, volt
6	a, én	2	VA	la, ló
7	VA	1	ló	ság
8	ló	1	ság	ot
9	em, ság	2	ot	PAUSE, STOP
240	STOP	1	Azt	KÉR
1	te	1	TOL	em
2	STOP	1	Jól	van
3	Jól, od	2	van	NEK, PAUSE
4	PAUSE, ben	2	majd	CSI, csak
5	majd	1	CSI	nál
6	CSI, SAJ	2	nál	ok, ta
7	AZ, nál	2	ok	ban, én
8	PIL, VA	2	la	mit, nat
9	PAUSE, nem	2	TUD	om, ta
250	MEG	1	szeret	ÚJ
1	szeret	1	ÚJ	ra
2	s, volt	2	AZ	ok, zal
3	AZ	1	zal	LE
4	LE	1	vel	et
5	et	1	írt	az
6	STOP, s	2	AB	2-ban
7	MEG	1	hívta	EB
8	STOP, az, hívta	3	EB	bol, 2-éd
9	2-EB	2	éd	STOP, re
260	STOP	1	El	is
1	LE	1	vél	MÁS
2	ez, vél	2	MÁS	kor, nap
3	MÁS, mad	2	nap	PAUSE, jött
4	s	1	HAR	mad
5	HAR	1	mad	nap
6	nap	1	jött	a
7	STOP	1	FÖL	vez

8	KI	1	rályt	a
9	PA	1	lo	tá
270	lo	1	tá	ba
1	STOP	1	Ott	már
2	volt	1	TER	ít
3	TER	1	ít	ve
4	ít	1	ve	az
5	az	1	ASZ	tal
6	ASZ	1	tal	két
7	két	1	SZEM	ély
8	SZEM	1	ély	re
9	LE	1	ül	tek
280	MEG	1	kós	tol
1	KI, kós	2	tol	HAL, ta
2	LE	1	vest	PAUSE
3	is, szul	2	TET	te, ted
4	kor, te	2	MIND	ig, járt
5	MIND	1	járt	a
6	a	1	KAN	al
7	2-PAUSE	2	OLY	2-an
8	2-an	2	SÓT	2-lan
9	2-SÓT	2	lan	PAUSE, volt
290	STOP	1	GON	dol
1	GON	1	dol	ta
2	EB	1	bol	BI
3	bol	1	BI	zony
4	BI	1	zony	KI
5	KI	1	fel	ej
6	fel	1	ej	tet
7	a	1	TÖB	bi
8	TÖB	1	bi	ÉT
9	az, bi	2	ÉT	2-el
300	el	1	ben	majd
1	csak	1	lesz	STOP
2	2-STOP	2	De	ezt, nem
3	STOP	1	HORD	ták
4	HORD	1	ták	a
5	a	1	PE	cseny
6	PE	1	cseny	ék
7	cseny	1	ék	et
8	de	1	VIS	sza
9	VIS	1	sza	is
310	VI	1	het	ték
1	HA	1	rap	ott
2	PAUSE	1	ÍZ	et
3	et	1	len	volt
4	De	1	ezt	már
5	nem	1	HAGY	ta
6	ta	1	szó	NÉL
7	szó, só	2	NÉL	2-kül
8	2-NÉL	2	kül	STOP, SÜT
9	STOP, azt, nem, tol	4	HAL	lod, 2-lot, tak
320	HAL	1	lod	e

1	PAUSE	1	ÖCS	ém
2	ÖCS	1	ém	PAUSE
3	hát	1	MILY	en
4	en	1	SZA	kács
5	SZA	1	kács	od
6	kács	1	od	van
7	NEK	1	ed	PAUSE
8	hogy	1	só	NÉL
9	kül, val	2	SÜT	2-foz
330	2-SÜT	2	foz	PAUSE, ez
1	STOP	1	SÓ	val
2	SÓ	1	val	SÜT
3	MOND, lot	2	tam	PAUSE, hát
4	hogy	1	BÁTY	ám
5	ám	1	UR	am
6	UR	1	am	nem
7	ne	1	TEGY	en
8	azt	1	ROS	szul
9	ROS	1	szul	TET
340	TET	1	ted	PAUSE
1	már, én	2	NAGY	2-on
2	2-NAGY	2	on	PAUSE, SZER
3	lot	1	tad	PAUSE
4	á	1	tól	PAUSE
5	a	1	PIL	la
6	la	1	nat	ban
7	ban	1	KINY	ílt
8	KINY	1	ílt	az
9	az	1	AJ	tó
350	AJ	1	tó	PAUSE
1	BE	1	lép	ett
2	rály	1	né	PAUSE
3	STOP	1	Hej	PAUSE
4	IS	1	ten	em
5	PAUSE	1	ÖR	ült
6	ÖR	1	ült	az
7	STOP	1	Mert	SAJ
8	Mert	1	SAJ	nál
9	EL	1	ker	get
360	STOP	1	Most	NEK
1	i	1	ad	ta
2	nagy	1	obb	OR
3	STOP	1	Még	ma
4	is	1	ÉL	nek
5	ÉL	1	nek	PAUSE
6	HAL	1	tak	STOP



SALT 2: INCREMENTAL EXTRACTION OF GRAMMAR BY SIMPLISTIC RULES

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Abstract

This e-paper continues the examination of language as a quasi-molecular system from the point of view of a chemist who happens to ask, “What if the words were atoms?” Previously, a scheme of incremental language acquisition, based on very few and simple chemistry-inspired principles, was described on the example of Hungarian folktale *A Só* (Salt). In this e-paper, the principles are further applied to a sequence of acquisition steps. The process does not include any numerical calculations. The elementary acts of analysis and extraction are regarded as binary encounters of quasi-molecules: small linear sequences of “atoms” of language negotiate the outcome of the “collision.” A concept of **natural** computing in language evolution and acquisition is discussed.

KEYWORDS: language acquisition, bootstrapping, pattern theory, chemistry, automatic translation, Turing test, Hungarian language, speech generation, semantics, robot-child, robot communication, incremental learning, grammar extraction, language acquisition device.



This e-paper is a further continuation of the examination of language as a quasi-molecular system from the point of view of a chemist who happens to ask, “What if the words were atoms?” For the explanatory and introductory material, as well as the text and translation of the Hungarian tale *Salt*, see SALT [1], where more references could be found. The overall intent can be formulated as application of chemical ideas to subjects outside chemistry: mind, language, society, and technology. While physicists have been doing that with physical ideas for over one hundred years, some chemists are only now slowly and timidly coming to the realization that chemistry might carry its own extra-chemical message.

The purpose of SALT 2 is to see if there is some bread to SALT [1]. The latter is absolutely necessary for understanding SALT 2. In a preliminary fashion, I attempt to test the outcome of SALT experiment for any, however early, promise to be used for linearization of thought structure. The latter is understood in terms of Pattern Theory as a configuration characterized by content, connector, and their quantitative measure [2].

One of the main stimuli of this embryonic work is to develop basic principles that could represent the process of **individual** language acquisition by a **robot-child**, whether realistic or not, in all concrete detail, without being overshadowed by mathematical

equations, graphs, numbers, and collective behavior. This is a typically chemical manner of investigation, embodied in the structural chemical equations. Ideally, they represent a detailed sequence of all stable and ephemeral states of the reaction in terms of **individual** atoms and bonds in participating molecules.

A possible application of this framework, if it turns out promising, is robotic communication based on grammar and lexicon **acquired** with minimal assistance and in conditions of **poverty of stimulus**. The **robot-child**, as the model can be called, has to go from infancy to the beginning of maturity when speech is mastered and active intentional learning becomes possible. Infants do not do that by reading *The Wall Street Journal*. Although the term bootstrapping, used in various meanings, is vague, it seems appropriate for the pre-learning mechanism. Its mechanistic and automatic nature resonates well with the term Language Acquisition **Device** (Chomsky).

While loose ends and questions hanging in the air can be clearly seen in this experiment, some excuse is that we all started with baby talk.

In SALT 2 I use larger fragments of input than in SALT, in order to faster accumulate the representation of a larger text, but shorter ones work similarly.

The problems of semantics are considered here least if all, although some initial idea will be put forward: semantics is **possibly** as presentable in triangles as syntax in triplets, i.e., squashed triangles.

I perform some easy operations, like input rewriting and haplology elimination, manually, while more cumbersome ones, like generating comprehensive tables of bonds and categories (CATS), are done with MATLAB codes (can be sent on request).

No explicit numerical calculations are involved.

The MATLAB output needs some simple manipulations with MS Word in order to convert it to tables in document format. Macros can be used.

The following six **steps** of acquisition are described with a diminishing degree of detail. The stressed syllables are capitalized.

STEP 1

INPUT 1

P1=char ('volt', 'EGY', 'szer', 'egy', 'Ö', 'reg', 'KI', 'rály', 'PAUSE', 'és', 'HÁ', 'rom', 'szép', 'LE', 'ány', 'a', ...
 'STOP', 'az', 'Ö', 'reg', 'KI', 'rály', 'SZER', 'et', 'te', 'VOL', 'na', 'mind', 'a', 'HÁ', 'rom', 'LE', 'ány', 'át', 'FÉRJ', ...
 'hez', 'AD', 'ni', 'STOP', 'ez', 'nem', 'is', 'lett', 'VOL', 'na', 'NE', 'héz', 'mert', 'HÁ', 'rom', 'OR', 'szág', 'a', ...
 'volt', 'PAUSE', 'mind', 'a', 'HÁ', 'rom', 'LE', 'ány', 'á', 'ra', 'JUT', 'ott', 'EGY', 'egy', 'OR', 'szág', 'STOP');

'START' and 'END' are added to P1:

P1=char ('START', 'volt', 'EGY', , 'OR', 'szág', 'STOP', 'END');

output:

1. Generators and triplets

Command: ms, dsgn .

ms (mindset) compiles structure **G** in which every generator enters only once.

dsgn (display generators) displays the triplets.

GENERATOR SPACE 1

P =72, G =44 (72 partly repeating and 44 different generators in input) .

The left and right neighbors are preceded by the number of their occurrences.

The occurrences of central generators are in Column 4.

G: GENERATOR SPACE 1				
1	2	3	4	5
No.	LEFT NEIGHBOR	G	No. of entries	RIGHT NEIGHBOR
1	START	START	1	volt;
2	START; a;	volt	2	EGY; PAUSE;
3	ott; volt;	EGY	2	egy; szer;
4	EGY;	szer	1	egy;
5	EGY; szer;	egy	2	OR; Ö;
6	az; egy;	Ö	2	2-reg;
7	2-Ö;	reg	2	2-KI;

8	2-reg;	KI	2	2-rály;
9	2-KI;	rály	2	1-PAUSE; SZER;
10	rály; volt;	PAUSE	2	mind; és;
11	PAUSE;	és	1	HÁ;
12	2-a; mert; és;	HÁ	4	4-rom;
13	4-HÁ;	rom	4	2-LE; OR; szép;
14	rom;	szép	1	LE;
15	2-rom; szép;	LE	3	3-ány;
16	3-LE;	ány	3	a; á; át;
17	2-mind; szág; ány;	a	4	2-HÁ; STOP; volt;
18	a; ni; szág;	STOP	3	END; az; ez;
19	STOP;	az	1	Ő;
20	rály;	SZER	1	et;
21	SZER;	et	1	te;
22	et;	te	1	VOL;
23	lett; te;	VOL	2	2-na;
24	2-VOL;	na	2	NE; mind;
25	PAUSE; na;	mind	2	2-a;
26	ány;	át	1	FÉRJ;
27	át;	FÉRJ	1	hez;
28	FÉRJ;	hez	1	AD;
29	hez;	AD	1	ni;
30	AD;	ni	1	STOP;
31	STOP;	ez	1	nem;
32	ez;	nem	1	is;
33	nem;	is	1	lett;
34	is;	lett	1	VOL;
35	na;	NE	1	héz;
36	NE;	héz	1	mert;
37	héz;	mert	1	HÁ;
38	egy; rom;	OR	2	2-szág;
39	2-OR;	szág	2	STOP; a;
40	ány;	á	1	ra;
41	á;	ra	1	JUT;
42	ra;	JUT	1	ott;
43	JUT;	ott	1	EGY;
44	STOP;	END	1	END

Extraction of CATS and BONDS implements the following simplistic rules:

RULE 1: Adjacency A—B is registered as bond if {A—B } repeats two or more times.

RULE 2: If {A—B, A—C } or {D—A , E—A }, A is a generator.

RULE 3. Haplology is eliminated.

RULE 4. If $\{A-B, A-C\}$, then **A** is a **RIGHT CAT** with domain $\{B,C\}$. If $\{B-A, C-A\}$, then **A** is a **LEFT CAT** with domain $\{B,C\}$.

EXAMPLES:

1. Bonds **a—HÁ** and **mind—a** contain generator **a**, which is encountered also in doublets **ány—a** and **a—volt**. Therefore, they cannot be qualified as very stable blocks, but could remain as background weak bonds.

Doublets **a—HÁ** and **a—volt** form right category (RIGHT CAT) **a—{HÁ, volt}**; doublets **mind—a** and **ány—a** form left category (LEFT CAT) **{mind, any}—a**.

2. In the following bond sequences the middle doublet is removed to eliminate haplology:

$\{\ddot{O}-\text{reg}, \text{reg}-\text{KI}, \text{KI}-\text{rály}\} \rightarrow \{\ddot{O}-\text{reg}, \text{KI}-\text{rály}\}$

$\{\text{HÁ}-\text{rom}, \text{rom}-\text{LE}, \text{LE}-\text{ány}\} \rightarrow \{\text{HÁ}-\text{rom}, \text{LE}-\text{ány}\}.$

3. **KI** and **rály** in INPUT 1 occur twice and **only as a doublet**. This is why they are qualified as a bond **KI_rály**, see below. The block further becomes a generator.

Under these circumstances **RULE 2** means that **CAT** is a generator. The difference is that **RULE 2** is applicable to **new** input, in which only **B** and **C** are known, while **RULE 4** applies to known generators. More important, **RULE 2** can be applied to levels below syllables. This difference is subtle and both rules can be combined.

2. Bonds

command: cblr (cats, bonds, left, right) ; it extracts bonds and CATs (categories) .

BONDS 1 output			
6	7	1	Ö_reg
7	8	2	reg_KI
8	9	3	KI_rály
12	13	4	HÁ_rom
13	15	5	rom_LE
15	16	6	LE_ány
17	12	7	a_HÁ
23	24	8	VOL_na
25	17	9	mind_a
38	39	10	OR_szág



BONDS 1 edited	
Ö_reg	
KI_rály	
HÁ_rom	
LE_ány	
VOL_na	
OR_szág	

Haplology is eliminated. BONDS with PAUSE and STOP are ignored in this experiment, although they can be meaningful.

3. CATS (CATs, categories)

LEFT CAT has its domain on the left, **RIGHT CAT** has its domain on the right.

LEFT CATS 1		
	domain	CAT
1	START, a	volt
2	ott, volt	EGY
3	EGY, szer	egy
4	az, egy	Ö
5	rály, volt	PAUSE
6	a, mert, és	HÁ
7	rom, szép	LE
8	mind, szág, ány	a
9	a, ni, szág	STOP
10	lett, te	VOL
11	PAUSE, na	mind
12	egy, rom	OR

RIGHT CATS 1		
	CAT	domain
1	volt	EGY, PAUSE
2	EGY	egy, szer
3	egy	OR, Ö
4	rály	PAUSE, SZER
5	PAUSE	mind, és
6	rom	LE, OR, szép
7	ány	a, á, át
8	a	HÁ, STOP, volt
9	STOP	END, az, ez
10	na	NE, mind
11	szág	STOP, a

CATS with “mute” generators **START**, **END**, and **STOP** (highlighted) are erased in this experiment) if there is only one more generator except the mute one; if more (see line 8 in **RIGHT CATS 1**), the mute one is erased.

LEFT CATS 1 (edited)		
1	ott, volt	EGY
2	EGY, szer	egy
3	az, egy	Ö
4	a, mert, és	HÁ
5	rom, szép	LE
6	mind, szág, ány	a
7	lett, te	VOL
8	egy, rom	OR

RIGHT CATS 1 (edited)		
1	EGY	egy, szer
2	egy	OR, Ö
3	rom	LE, OR, szép
4	ány	a, á, át
5	a	HÁ, , volt
6	na	NE, mind

This concludes the analysis of **OUTPUT** from **INPUT P1**.

To prepare **OUTPUT 1**, for the next input **P2**, **P1** is rewritten (compacted) into **PP1** in accordance with the table of **BONDS**. The final 'END' is removed.

OUTPUT 1, compacted

PP1 = char('START', 'volt', 'EGY', 'szer', 'egy', 'Öreg', 'Király', 'PAUSE', 'és', 'Három', 'szép', 'LEány', 'a', ...
 'STOP', 'az', 'Öreg', 'Király', 'SZER', 'et', 'te', 'VOLna', 'mind', 'a', 'Három', 'LEány', 'át', 'FÉRJ', 'hez', ...
 'AD', 'ni', 'STOP', 'ez', 'nem', 'is', 'lett', 'VOLna', 'NE', 'héz', 'mert', 'Három', 'ORSzág', 'a', 'volt', 'PAUSE', ...
 'mind', 'a', 'Három', 'LEány', 'á', 'ra', 'JUT', 'ott', 'EGY', 'egy', 'ORSzág', 'STOP');

After any step of acquisition is completed, the subsequent input cannot be perceived on the same terms as the previous one. If some stable BONDS were recorded, the next input is perceived in terms of bonded doublets as generators. This seems to be the major difference between the statistical analysis of a corpus and the autonomic bootstrapping. **In the eyes and ears of robot-child, the world gradually takes meaning**

through discovering its regularity. This process can be visualized as the moving borderline between **the old** and **the new**, as in walking through darkness with a flashlight.

Strictly speaking, all **BONDS** and **CATS** structures can be remembered, but for the purpose of illustration only the edited ones will be kept in memory and transferred to the next STEP.

Note that addresses in **G** may change from step to step, but addresses in **BONDS** and **CATS** always correspond to the current space **G**.

STEP 2

OUTPUT 1 changes the **perception** of the next **INPUT 2** so that the bonded syllables are combined into **words**, whether complete or incomplete. Haplology is eliminated.

INPUT 2

P2=char('HA', 'nem', 'a', 'HOGY', 'an', 'nincs', 'HÁ', 'rom', 'EGY', 'for', 'ma', 'AL', 'ma', 'PAUSE', 'úgy', 'a', ...
'HÁ', 'rom', 'OR', 'szág', 'sem', 'volt', 'EGY', 'for', 'ma', 'STOP', 'azt', 'MOND', 'ta', 'EGY', 'szer', 'a', 'KI', ...
 'rály', 'a', 'LE', 'ány', 'a', 'i', 'nak', 'hogy', 'AN', 'nak', 'AD', 'ja', 'a', 'LEG', 'szebb', 'OR', 'szág', 'át', 'PAUSE', ...
 'A', 'mely', 'ik', 'öt', 'PAUSE', 'LEG', 'job', 'ban', 'SZER', 'e', 'ti', 'STOP');

Compacting the input along BONDS 1:

P2=char('HA', 'nem', 'a', 'HOGY', 'an', 'nincs', 'HÁ', 'rom', 'EGY', 'for', 'ma', 'AL', 'ma', 'PAUSE', 'úgy', 'a', ...
'HÁrom', 'ORszág', 'sem', 'volt', 'EGY', 'for', 'ma', 'STOP', 'azt', 'MOND', 'ta', 'EGY', 'szer', 'a', 'Király', 'a', ...
 'LEány', 'a', 'i', 'nak', 'hogy', 'AN', 'nak', 'AD', 'ja', 'a', 'LEG', 'szebb', 'ORszág', 'át', 'PAUSE', ...
 'A', 'mely', 'ik', 'öt', 'PAUSE', 'LEG', 'job', 'ban', 'SZER', 'e', 'ti', 'STOP');

Next, PP1 and P2 are concatenated: P=strvcat(PP1, P2, 'END');

output:

The complete **G TABLE** is omitted.

1.Bonds 2

BONDS 2 add up to BONDS 1

BONDS 2 output	
1	volt_EGY
2	EGY_for
3	EGY_szer
4	Öreg_Király
5	Három_LEány
6	Három_ORszág
7	LEány_a
8	a_Három
9	STOP_END
10	mind_a
11	for_ma



BONDS 2 edited; strong bonds in bold	
1	volt_EGY
2	EGY_szer
3	Öreg_Király
4	Három_LEány
5	Három_ORszág
6	LEány_a
7	a_Három
8	mind_a
9	EGY_for_ma

BONDS 2 illustrate the fluid and provisional character of **BONDS** and the idea of equilibrium.

BONDS 1 include **Ö_reg** and **KI_rály**. There is a persistent tendency for their adjacency, so that until further solidification of bonds there is an equilibrium **soup**:

{Ö , reg , KI , rály , Ö_reg , KI_rály , Ö_reg_KI_rály }

The quantitative aspect is ignored here. The “weights” in the soup correspond to concentrations in chemistry and probabilities in Pattern Theory [2]. The term “weight,” an artifact of the first neural networks, seems very inappropriate because, unlike concentration, probability, and even energy, it is not normalized. The comparison with neural networks, however, is avoided here. The position of the **equilibrium** depends on the topic, context, and previous history. We tend to speak in larger blocks when the subject is familiar and frequent. We might stumble on an unfamiliar terrain.

The concept of equilibrium cannot be applied to the mind as a whole, where equilibrium is continuously shifting because of the aging of memory traces and the influx of new traces. In physical sense, is never achieved in any living system.

Gradually the representation becomes more and more coarse as the bonds and categories solidify and the atomic entries become tagged by their categories. This process of tagging is nothing mysterious: a generator is in equilibrium with all its neighbors and **a category is the neighbor of its entire domain**. Categories overlay **star topology** on **tree topology**.

Distinctively, the **perception also becomes coarser**: from sounds to phonemes to syllables to morphemes to words to expressions.

The idea of local equilibrium that I am trying to convey, not for the first time, but still with a great difficulty, is very simple in chemistry. The best way is just to look into the textbook of general chemistry, although the illustrative material is scattered all over the course. A chemical substance is always in equilibrium with all its possible fragments, down to the atoms, but the concentration of all or absolute majority of fragments or transposition at certain conditions (regarded “normal” in chemistry, physics, and human environment) is practically zero.

Example: Vinegar is acetic acid CH_3COOH in water. It is in equilibrium with its two fragments: $\text{CH}_3\text{COOH} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}^+$ (it is H^+ that tastes sour, whatever its origin). Theoretically, there could be equilibriums along all bonds, for example, $\text{CH}_3\text{COOH} \rightleftharpoons \text{CH}_3\text{CO}^+ + \text{OH}^-$, which at normal conditions is completely shifted to the left.

Nevertheless, the chemical transformations run through such rare, unstable, and improbable states. Otherwise, everything that could chemically happen with the atoms of our body would happen in an instant.

In terms of practical computation, equilibrium means that most of the memory of your personal computer is inaccessible **at the moment**, which only shows how unnatural computers are in their accessibility. It is hard not to remark that in the digital age the

structure of society becomes unnatural if your most intimate social identity tags become accessible.

As a further illustration, recall how difficult it could be sometimes to retrieve a name of a person or location. But if we remember its fragment or any link, for example, that it is something related to horses, the name comes up: Mr. Rein? Mr. Spur? Mr. Bay? Mr. Hay? Mr. Oats, of course! (the idea is borrowed from a short story by Chekhov). This demonstrates the difference between the Hopfield network and human memories, although the former has the ability of a retrieval by fragment.

The memory I have in mind does not have addresses in the sense ROM and RAM have. The address of the natural memory cell is anything in equilibrium with the content of the cell. This can be either less (first letter of the name Oats) **or more** (“horses”) than the cell content. I believe neurophysiology has its own view of the problem, but in psychology it has been known since long as association. Note that the behavior of the acetic acid in the above example is called dissociation from left to right and association from right to left.

Bonds **HÁrom—LEány** and **HÁrom—ORSzág** dissociate and associate in the same manner as acetic acid. Suppose robot-child with *Salt* as its only life experience hears the word **HÁrom** (“three”). The words **LEány** (“girl”) and **ORSzág** (“land”) will immediately activate in its memory.

2. CATS 2

LEFT CATS 2 (edited)		
1	a, sem	volt
2	ott, rom, ta, volt	EGY
3	EGY, szer	egy
4	az, egy	Öreg
5	a, Öreg	Király
6	a, mert, és	HÁrom
7	HÁrom, a, szép	LEány
8	Király, LEány,	a

	ORSzág, ja, mind, nem, szer, úgy	
9	Király, ban	SZER
10	lett, te	VOLna
11	LEány, ORSzág	át
12	hez, nak	AD
13	HA, ez	nem
14	HÁrom, egy, szebb	ORSzág
15	AL, for	ma

16	AN, i	nak
----	-------	------------

9	a	HOGY, HÁrom, Klrály, LEG LEány , i, volt
11	SZER	e, et
12	VOLna	NE, mind
14	AD	ja, ni
15	nem	a, is
16	ORszág	, a, sem, át
17	nak	AD, hogy
18	LEG	job, szebb

RIGH CATS 2 (edited)		
2	EGY	egy, for, szer
3	szer	a, egy
4	egy	ORszág, Öreg
5	Klrály	SZER, a
7	HÁrom	LEány, ORszág, szép
8	LEány	a, á, át

The new CATS 2 are in bold type. The previous CATS 1 may still be in memory.

OUTPUT 2 (compact)

PP2=char('START', 'volt', 'EGYszer', 'egy', 'Öreg', 'Klrály', 'PAUSE', 'és', 'HÁrom', ...
'szép', 'LEány', 'a', 'STOP', 'az', 'Öreg', 'Klrály', 'SZER', 'et', 'te', 'VOLna', 'mind', ...
'a', 'HÁrom', 'LEány', 'át', 'FÉRJ', 'hez', 'AD', 'ni', 'STOP', 'ez', 'nem', 'is', 'lett', ...
'VOLna', 'NE', 'héz', 'mert', 'HÁrom', 'ORszág', 'a', 'volt', 'PAUSE', 'mind', 'a', ...
'HÁrom', 'LEány', 'á', 'ra', 'JUT', 'ott', 'EGY', 'egy', 'ORszág', 'STOP', 'END', 'HA', ...
'nem', 'a', 'HOGY', 'an', 'nincs', 'HÁ', 'rom', 'EGYforma', 'AL', 'ma', 'PAUSE', ...
'ügy', 'a', 'HÁrom', 'ORszág', 'sem', 'volt', 'EGYforma', 'STOP', 'azt', 'MOND', ...
'ta', 'EGYszer', 'a', 'Klrály', 'a', 'LEány', 'a', 'i', 'nak', 'hogy', 'AN', 'nak', 'AD', 'ja', ...
'a', 'LEG', 'szebb', 'ORszág', 'át', 'PAUSE', 'A', 'mely', 'ik', 'öt', 'PAUSE', ...
'LEG', 'job', 'ban', 'SZER', 'e', 'ti', 'STOP');

GRAMMAR 2

Until now we were manipulating syllables in a formal manner, supposedly not knowing what they meant, although I felt a constant pressure of meaning. Now we can try to tentatively interpret what it all means. Translations are given for words and some morphemes/lexemes.

Left or right is indicated by letters L and R: EGY L means LEFT CAT ‘EGY’.

NOTE. This example reminds about the agglutination in Hungarian:

'LEány', 'a', 'i', 'nak' = “girl,” “his/her,” “Plural,” “Dative”;

'LEányainak' = [give] “to his/hers girls”

Most probably, each of the countless blocks of morphemes in such languages as Hungarian, Finnish, Russian, and Turkish, are acquired by children as a whole. As a speaker of Russian, however, I must note that sometimes the trailing endings need some small but perceptible time to arrange in order before saying. I would not be able to use the following word up to, probably, the age of 7 or 8, and even now I would avoid it by all means:

проигрывающиеся

pro-igr-yva-yu-shchi-e-sya (7 morphemes)

[those that] can be played (playable) [for example, on DVD player]

or: [those that] are being played now; **igr** is the stem (“play”)

Table GRAMMAR 2 is compiled manually from **CATS 2**.

GRAMMAR 2					
	LEFT	CAT	RIGHT	INTERPRETATION	LABEL
1		EGY R “one”	-egy , -szer EGYegy, “one” EGYszer “once”	Semantics (“one”)	EGY R
2	-ott, -ta, volt Past , “was”	EGY L “one”		Verb (Past)	volt
3	az, egy	Öreg “old”		Article	egy
4	a, Öreg	Király “king”		Adjective	Öreg
5		egy “a”	ORszág, “land” Öreg “old”	Noun Single Indefinite	ORszág
6	HÁrom, a, szép “three”, “the”,	LEány “girl”		Noun group (Numeral, Adjective)	szép

	“beautiful”				
7		Három “three”	LEány, ORszág szép	Numeral	Három
8		LEány	-a, -á, -át	Possessive	-a
9	LEány, ORszág	át		Noun Possessive + Accusative.	át
10	-hez, -nak “to”, Dative	AD “give”		case endings Allative, Dative	-hez
11		AD	-ja, 3rd Person, -ni Infinitive	Verb	AD R
12	Három, egy, szebb “three”, “a”, “best”	ORszág “land”		Noun group	ORszág
13	Alma “apple,” forma “form”	(ma)		(sound)	
14	AN, -i- ANnak “to that one” -i- Plural	-nak		Dative	nak
15		STOP	az, azt, ez “the”, “this”	Article, Pronoun, (Sentence start)	STOP R
16		SZER	-e, -et SZEReti “loves” SZERet “loved” 3 rd Person	See comments to STEP 4	SZER R
17		LEG	-jobb, -szebb (LEGszebb “best”)	Superlative	LEG

IMPORTANT: Interpretation relates to the domain of CAT, not to the CAT itself.

I hope the **GRAMMAR 2** table speaks for itself, very much like an infant, as it is supposed to. What I see in it is the very beginning of crystallization of **individual** grammar in the **individual** mind of the robot-child who has never heard anything but the story of Salt. If *Salt* is its only experience, semantics is absent.

But how are categories labeled in the mind of an infant? Certainly not by terms of grammar. Of course, the category is just a generator and it is labeled just by its individuality of a set member. But some first words that enter CATS may contribute themselves as internal labels for **patterns of grammar**. This is reasonable in case of LEFT CATS, but for RIGHT CATS the name of the CAT can be taken as label. I wonder

if this is because Hungarian is left-branching. Will that be different in Spanish? To speculate, **the first impressions of robot-child imprint large subsequent categories of whether syntax or semantics** (I begin to suspect that their opposition may be as useful but as artificial as the concept of syllable). Could this work for a real child? It is quite probable that the first impressions of the child imprint internal labels for large **natural** categories of light, darkness, comfort, discomfort, hunger, satisfaction, fear, and joy, from which the tree of knowledge grows. Ulf Grenander describes in *Patterns of Thought* [2] the outer branches of the tree.

STEP 3

In subsequent STEPS only compacted new inputs will be shown.

INPUT 3

P3=char('FEL', 'elj', 'NEK', 'em', 'PAUSE', 'ÉD', 'es', 'LE', 'ány', 'om', 'PAUSE', 'hogy', 'SZER', 'etsz', ...
 'EN', 'gem', 'PAUSE', 'KÉR', 'dez', 'te', 'a', 'LEG', 'i', 'dö', 'sebb', 'ik', 'et', 'STOP', 'mint', 'a', 'GA', 'lamb', ...
 'a', 'TISZ', 'ta', 'BÚZ', 'át', 'PAUSE', 'MOND', 'ta', 'a', 'LE', 'ány', 'STOP', 'hát', 'te', 'PAUSE', 'ÉD', 'es', ...
 'LE', 'ány', 'om', 'PAUSE', 'KÉR', 'dez', 'te', 'a', 'KÖZ', 'ép', 'söt', 'STOP', 'én', 'ügy', 'ÉD', ...
 'es', 'AP', 'ám', 'PAUSE', 'mint', 'FOR', 'ró', 'NYÁR', 'ban', 'a', 'SZEL', 'löt', 'STOP');

No compacting is needed

P =183 G =96

BONDS 3 and CATS 3 (Strong bonds are in bold type)

BONDS 3 edited
Öreg-Király
HÁrom-LEány
HÁrom-ORszág
LEány-a
LEány-om
a-HÁrom
a-LEG

a-LEány
te-a
mind-a
MOND-ta
ÉD-es
es-LEány
KÉR-dez
dez-te

RIGHT CATS 3	
volt	EGYforma, EGYszer PAUSE
EGYszer	a, egy
egy	ORszág, Öreg
Király	PAUSE, SZER, a
PAUSE	A, KÉR, LEG, MOND hogy, mind, mint, ÉD, és, úgy
Három	EGYforma, LEány, ORszág, szép
LEány	STOP, a, om, á, át
a	GA, HOGY, HÁrom, Király KÖZ, LEG, LEány, SZEL, TISZ
a	i, volt
STOP	END, FEL, HA, az, azt, ez, hát, mint, én
SZER	e, et, etsz
et	STOP, te
te	PAUSE, VOLna, a
VOLna	NE, mind
át	FÉRJ, PAUSE
AD	ja, ni
nem	a, is
ORszág	STOP, a, sem, át
EGYforma	AL, STOP
úgy	a, ÉD
ta	BÚZ, EGYszer, a
i	dő, nak
nak	AD, hogy
hogy	AN, SZER
LEG	i, job, szebb
ik	et, őt
ban	SZER, a
es	AP, LEány
mint	FOR, a

LEFT CATS 3	
START, a, sem	volt
ta, volt	EGYszer
EGY, EGYszer	egy
az, egy	Öreg
a, Öreg	Király
Király, em, gem, ma, om te, volt, ám, át, őt	PAUSE
a, mert, nincs, és	Három
Három, a, es, szép	LEány
EGYszer, Király, LEány ORszág,	a
ban, ja, lamb mind, mint, nem, ta, te, úgy	a
EGYforma, LEány, ORszág, a, et, lőt, ni, sőt, ti	STOP
Király, ban, hogy	SZER
SZER, ik	et
dez, et, hát	te
lett, te	VOLna
PAUSE, VOLna	mind
BÚZ, LEány, ORszág	át
hez, nak	AD
HA, ez	nem
Három, egy, szebb	ORszág
Három, volt	EGYforma
PAUSE, én	úgy
PAUSE, azt	MOND
MOND, TISZ	ta
LEG, a	i
AN, i	nak
PAUSE, nak	hogy
PAUSE, a	LEG
mely, sebb	ik
NYÁR, job	ban
PAUSE, úgy	ÉD
PAUSE, STOP	mint

Some Hungarian morphemes, such as *a* and *t*, are used as markers in several roles across various parts of speech. The red border in the CATS 3 tables encloses an example of how this multifunction can be dealt with. The lines of CAT *a*, both LEFT and RIGHT, are split depending on the **stress** of the syllables in the domain.

Note that in Hungarian the possessor is unmarked, while the possession is:

A Király ORszága , “The King land-**his**” , “The King’s land,”

In LEFT CATS, if a precedes a stressed syllable, a strong hypotheses of robot-child is that a is the definite article. If the next after a syllable is unstressed or the word is monosyllabic, it is a possession mark: **ORszág****a** volt , “his/her-land was.”

In RIGHT CATS, if a **noun** is followed by a, a somewhat weak hypothesis can be formed that a marks a possession: **LEány****a** , “his/her-girl.” Otherwise, it can be the definite article.

BONDS 1-3, edited
BONDS 2
MOND _ta
KÉR _dez
ÉD _es
BONDS 2
EGY _for_ma
EGY _szer
volt_EGY
Öreg_Király
Három_LEány

Három_ORszág
LEány_a
a_Három
mind_a
BONDS 1
Ö _reg
KI _rály
HÁ _rom
LE _ány
VOL _na
OR _szág

Blocks of words are not strong bonds. I left them in the BONDS 1-3 table to illustrate the semantic and **contextual** significance of longer blocks: **volt_EGYszer** “there was once,” **Öreg—Király** “old king,” **Három—LEány** “three girls,” **Három—ORszág** “three lands.” The plural of the noun after a numeral is unmarked in Hungarian.

LEFT CATS 3 (edited)	
ta, volt	EGYSzer
KIrály, em, gem, ma, om	PAUSE
te, volt, ám, át, öt	
a, mert, nincs, és	HÁrom
HÁrom, a, es, szép	LEány
EGYSzer, KIrály, LEány	a
ORSzág,	
ban, ja, lamb	a
mind, mint, nem, ta, te, úgy	
KIrály, ban, hogy	SZER
SZER, ik	et
dez, et, hát	te ??? TE
lett, te	VOLna
BÚZ, LEány, ORszág	át
hez, nak	AD
HA, ez	nem
HÁrom, egy, szebb	ORSzág
HÁrom, volt	EGYforma
MOND, TISZ	ta
LEG, a	i
AN, i	nak
mely, sebb	ik
NYÁR, job	ban

RIGHT CATS 3 (edited)	
volt	EGYforma, EGYszer
EGYSzer	a, egy
egy	ORSzág, Öreg
HÁrom	EGYforma, LEány, ORszág, szép
LEány	-a, -om, -á, -át
a	GA, HOGY, HÁrom, KIrály KÖZ, LEG, LEány, SZEL, TISZ
a	i, volt
SZER	e, et, etsz
AD	ja, ni
nem	a, is
ORSzág	a, sem, át
i	dő, nak
nak	AD, hogy
LEG	i, job, szebb
ik	et, öt
ban	SZER, a
es	AP, LEány
mint	FOR, a

GRAMMAR 3

STEP 3 does not add much to the grammar. The following are some new or expanded old categories:

	LEFT	CAT	RIGHT	INTERPRETATION	Label
GRAMMAR 2 is here					
18	-mely-, -sebb- (Amelyik “which,” LEGsebbik “which is the most beautiful”)	ik		Suffix of “adjectivity,” working as an object pronoun	ik
19	HA, ez (HANem “however” ez nem “this is not”)	nem “not, no”		Semantics: negativity	nem
20		SZER	e, et, etsz	See comments to STEP 4	

COMMENTS to STEP 3:

1. Category { **NYÁR, job** } **ban** is a wrong hypotheses. **NYÁRban** means “in the summer”, but in the phonological **LEG-job-ban** “best of all”, the adverb morpheme is **an**, not **ban**, “in”. Morphology requires **LEG-jobb-an**. The double **b** is a stem variation.

NOTE. The struggle of morphology and phonetics raises a lot of dust over the notion of syllable. This problem has been repeatedly addressed in the literature, sometimes in strong words against phonology, but is too technical to discuss here. Regarding Hungarian, I wish to refer to the ingenious solution found, as I suspect, by people at least partly outside linguistics. Instead of syllables, “half-syllables” were used as atoms of speech [3]. Examples: **ta-, a-, te-, le-, ke-** (first half-syllable), **-a, -e, -i, -ol, -el, -in, -ek** (second half), etc. 326 half-syllables

describe 95% of general Hungarian texts. It is, essentially, uses haplology as the means of “mutual recognition” of atoms of speech.

2. **PAUSE** in the left CAT 3 follows an unstressed syllable.

3. **MONDta** “said,” and **TISZta** “clean” are together for a wrong reason.

STEP 4

INPUT 4

P4=char('no', 'most', 'TÉ', 'ged', 'KÉRdez', 'lek', 'PAUSE', 'FOR', 'dult', 'a', 'LEG', 'kis', 'ebb', 'ik', 'hez', ...
 'STOP', 'MOND', 'jad', 'hogy', 'SZER', 'etsz', 'STOP', 'úgy', 'ÉD', 'es', 'AP', 'ám', 'PAUSE', 'a', 'HOGY', ...
 'az', 'EM', 'ber', 'ek', 'a', 'sót', 'PAUSE', 'FEL', 'el', 'te', 'a', 'KI', 'csi', 'Király', 'kis', 'asz', ...
 'szony', 'STOP', 'mit', 'BE', 'szélsz', 'te', 'PAUSE', 'FÖR', 'medt', 'rá', 'a', 'Király', 'STOP', 'ki', 'az', ...
 'UD', 'var', 'om', 'ból', 'de', 'még', 'az', 'ORszág', 'om', 'ból', 'is', 'PAUSE', 'STOP', 'ne', 'IS', 'lás', 'sa', 'lak', ...
 'PAUSE', 'ha', 'csak', 'EN', 'nyi', 're', 'SZER', 'etsz', 'STOP');

P =264 G =136

BONDS 4 (unedited)		
5	6	Öreg_Király
9	11	HÁrom_LEány
9	32	HÁrom_ORszág
11	12	LEány_a “his girl”
11	69	LEány_om, “my girl”
12	39	a_HOGY, “as”
12	9	a_HÁrom
12	6	a_Király
12	54	a_LEG
12	11	a_LEány
15	70	SZER_etsz “you (s.) love”
17	12	te_a
19	12	mind_a

51	15	hogy_SZER
68	11	ÉDes_LEány “dear girl”
69	7	om_PAUSE
69	124	om_ból “out of my”
70	13	etsz_STOP
73	17	KÉRdez_te “asked”
87	88	AP_ám “my father”
88	7	ám_PAUSE

The CATS are omitted at this step.

COMMENTS to STEP 4:

1. In STEP 4 BONDS and CATS add new words: **APám** , “my father,” suffix –**bol** “out of,” and the personal suffix category of possession –**om**, “my.” Due to the harmony of vowels, the marking morphemes belong to one of two phonetic series. The other “my” morpheme is –**am** as in **APám** . This is where **Rule 2** comes into play: –**am** and –**om** form a **phonetic** category –**m**, “my,” which is **not syllabic**. Harmony of vowels requires a separate non-morphemic and non-syllabic category of vowel type.

2. Line 20 in **GRAMMAR 3** is an evidence of confusion that comes from the fuzziness of syllable. I created the confusion by resisting the temptation to split **SZEReti** into **SZER-et-i**, as the morphology required, because **SZERet** is the stem of verb “to love”. There is no such word or stem as **szer**. There is not enough data for robot-child at this step to form the bond **SZER—et** , for which the rest of the tale will give enough evidence. The total count for the entire tale is 11:

1 SZER-et-te (he) loved	1 SZER-et-ik (he) loves
2 SZER-e-ti (he) loves	1 SZER-et-ték (they) loved
3 SZER-etsz (you) love	3 SZER-et-em (I) love

The syllabic division of **SZER-e-ti** and **SZER-etsz** conflict with morphology. There is a good chance, however, that the initial hypotheses in **STEPS 1 to 4** will be replaced by better founded ones. The morpheme **sz** , which is not exactly syllabic, will be differentiated phonetically.

Language acquisition certainly starts at phonemic level. I have already noted elsewhere that optimality principle of Prince and Smolensky, first developed in phonetics, is very chemically-friendly. Paradoxically, it might be easier to translate speech than text. This is a very intriguing problem, which will be left until better times, however.

3. Note the crystallization (highlighted yellow) of the definite article *a* and nouns *a_HÁrom*, “the three,” *a_Király*, “the king,” *a_LEány*, “the girl,” as well as the standard block *mind_a*, “each/all” + article, which could well be written as one word. Further, the verb forms become more solid: *KÉRdez_te*, “(he/she) asked.” This poses a question: how much strength should we attribute to the bonds? The answer is: I have no idea and this is exactly the point of the project. We should make a model and trust robot-child to tackle the problem on its own. Until that, my attribution of bold type to strong bonds is intuitive, which is not much better than arbitrary. Since I am familiar with the meaning of the words, I must be excluded from decision making. I realize that this is a truly heretic idea, but definitely not the only heretic idea in the realm of ideas, some of them later accepted. To reformulate this idea: I am forbidden to be the homunculus for robot-child because I have a mind of my own.

The last squeak of homunculus: “Should we cut **robot-child** into **Rotchild**? “

STEP 5

P5=char('Hl', 'á', 'ba', 'sirt', 'a', 'Klirály', 'kis', 'asz', 'szony', 'PAUSE', 'Hl', 'á', 'ba', 'MA', 'gyar', 'áz', ...
'ta', 'hogy', 'az', 'EM', 'ber', 'ek', 'SZER', 'et', 'ik', 'a', 'sót', 'PAUSE', 'VI', 'lág', 'gá', 'KEL', 'lett', ...
'hogy', 'MENJ', 'en', 'STOP', 'EL', 'in', 'dult', 'a', 'KI', 'csi', 'Klirály', 'kis', 'asz', 'szony', 'SÍR', ...
'va', 'PAUSE', 'és', 'BE', 'ért', 'egy', 'nagy', 'ER', 'dő', 'be', 'STOP', 'ON', 'nan', 'nem', 'is', 'ment', ...
'TO', 'vább', 'PAUSE', 'ott', 'élt', 'egy', 'DA', 'rab', 'ig', 'EGY', 'ma', 'gá', 'ban', 'STOP');

BONDS 5 (unedited)		
5	6	Öreg_Király
6	99	Király_kis
7	73	PAUSE_KÉRdez
7	68	PAUSE_ÉDes
7	8	PAUSE_és
9	11	HÁrom_LEány
9	32	HÁrom_ORszág
11	12	LEány_a
11	69	LEány_om
12	39	a_HOGY
12	9	a_HÁrom
12	110	a_KI
12	6	a_Király

12	54	a_LEG
12	11	a_LEány
12	108	a_sót
14	105	az_EM
15	16	SZER_et
15	70	SZER_etsz
17	7	te_PAUSE
17	12	te_a
19	12	mind_a
20	7	át_PAUSE
26	27	nem_is
33	136	á_ba
51	15	hogy_SZER
68	11	ÉDes_LEány

69	7	om_PAUSE
69	123	om_ból
70	13	etsz_STOP
73	17	KÉRdez_te
87	7	APám_PAUSE
98	12	dult_a
99	112	kis_asz

105	106	EM_ber
106	107	ber_ek
108	7	sót_PAUSE
110	111	KI_csi
111	6	csi_Király
112	113	asz_szony
135	33	HI_á

BONDS 5
edited
KIrály_kis
az_EM
SZER_et
á_ba

KÉRdez_te
kis_asz
EM_ber
ber_ek
KI_csi
asz_szony

The reason why I show the numbers of generators in BONDS tables is to illustrate the detection of haplogy. The numbers follow without interruption:

14	105	az_EM
105	106	EM_ber
106	107	ber_ek

Next CATS will be shown selectively because their interpretation will involve too much reference to their meaning. This will be difficult to follow without the knowledge of the language.

RIGHT CATS 5 (illustrative selections)		
RIGHT CAT	Domain	Interpretation
HÁrom “three”	EGYforma_LEány_ORszág_szép “equal,” “girl,” “land,” “beautiful”	Noun or Adjective
LEány	_a_om_á_át	Noun suffixes
a “the”	HÁrom, KIrály, LEány, “three,” “king,” “girl” (Nominative) sót, “salt (Accusative)”	Noun or numeral
et	ik, te	Verb suffixes
AD	ja, ni	Verb suffixes
LEG- “the most”	(i), job,kis, szebb “good,” “little,” “beautiful”	Superlative
ik	a, et, hez, őt	A very confused CAT

ÉDes “dear, sweet”	APám LEány “my father,” “girl”	Noun
KÉRdez	lek te	Verb suffixes

LEFT CATS 5 (selectively)		
Domain	LEFT CAT	Interpretation
MONDta, volt “said” “was”	EGYszer “once”	Standard block
HÁrom, a, szép, ÉDes “three”, “the,” “beautiful,” “sweet”	LEány “girl”	Noun group
LEány, ORszág, -var “girl,” “land,” “court” (second syllable)	-om “my”	Personal Possession

Note the following CAT:

a	HÁrom, KÍrály, LEány, sőt
----------	----------------------------------

in which **sőt** is the Object Case (Accusative) of **só** “salt.” Should I have capitalized monosyllabic nouns?

Anticipating the next shaky steps of the model, I hope that if **só** is going to be mentioned in various cases, the problem will be solved somehow. These are some of the later entries of **só** in the text: '**SÓtlan**', “saltless” ', '**SÓval**', “with salt,” as well as just **só**. But how exactly it is going to be solved, I don’t know. Listening to the sound track, I cannot decide whether it is really stressed, although it seems to be so in **a sőt** , “the salt (object).” The article **a** places it in the category of nouns.

My Russian ear is not used to distinguish between a long and a stressed vowel, which again brings us to the obvious idea that linguistics as exact natural science must start with phonemes. Chemistry starts with elements.

BONDS 5 edited		
6 99		KÍrály_kis
14 105		az_EM
15 16		SZER_et
33 136		á_ba
73 17		KÉRdez_te

99 112		kis_asz
105 106		EM_ber
106 107		ber_ek
110 111		KI_csi
112 113		asz_szony

BONDS 5 add words: **EM_ber_ek**, “people,” **KÍrály_kis_as_szony**, “princess” **KÉRdez_te**, “(he/she) asked.”

STEP 6

P6=char('EGYszer', 'MI', 'kor', 'már', 'egy', 'ESZT', 'en', 'dö', 'is', 'el', 'telt', 'PAUSE', 'ar', 'ra', 'JÁR', 'ta', ...
 'SZOM', 'széd', 'Király', 'fi', 'PAUSE', 'és', 'MEG', 'lát', 'ta', 'a', 'Királykisasszonyt', 'STOP', 'MEG', ...
 'tet', 'szett', 'a', 'Király', 'fi', 'nak', 'a', 'Királykisasszony', 'PAUSE', 'mert', 'A', 'kár', 'mi', 'lyen', 'PISZ', ...
 'kos', 'volt', 'a', 'RU', 'há', 'ja', 'PAUSE', 'szép', 'volt', 'KÜ', 'lön', 'ös', 'en', 'az', 'AR', 'ca', 'STOP', 'SZÉP', ...
 'en', 'MEG', 'fog', 'ta', 'a', 'KEZ', 'ét', 'PAUSE', 'HA', 'za', 'vez', 'et', 'te', 'a', 'PA', 'lot', 'á', 'já', 'ba', 'PAUSE', ...
 'és', 'két', 'HET', 'et', 'sem', 'várt', 'PAUSE', 'de', 'még', 'EGY', 'et', 'sem', 'de', 'TAL', 'án', 'még', 'egy', 'ÓR', ...
 'át', 'sem', 'PAUSE', 'és', 'MEG', 'es', 'küd', 'tek', 'STOP', 'END');

P =416 G =200

BONDS 6

BONDS 6 edited	
5 6	Öreg, Király
6 164	Király-fi (prince)
8 165	és, MEG
9 11	Három, LEány
9 31	Három, ORszág
11 12	LEány-a (his girl)
11 69	LEány-om (my girl)
12 38	a, HOGY
12 9	a, HÁrom
12 112	a, Kicsi
12 6	a, Király
12 113	a, Királykisasszony
12 53	a, LEG
12 11	a, LEány

12 110	a, sőt
14 107	az, EM
16 12	te, a
18 12	mind, a
25 26	nem, is
50 61	hogy, SZER
61 70	SZER, etsz
68 11	ÉDes, LEány
69 123	om, ból
73 12	KÉRdezte, a
76 45	et, sem
107 108	EM-ber (man)
107 108 109	EM-ber-ek (people)
112 113	Kicsi, Királykisasszony
124 125	de, még

We can see the development of an important generalization (highlighted yellow): the patterns of the definite article **a** and the subsequent noun group. The bond, therefore, can be completely described at the level of the interpreted CATS:

[Definite Article]—[Numeral, Adjective, or Noun]

or, to emphasize the higher level: **Article—Noun**

There are also case and possessive suffixes of a noun (highlighted green) and some stable expressions **mind a** (“all of the..., each of the...”) and **nem is** (“not so [bad]”)

RIGHT CATS 6 edited; selectively		Interpretation
volt	EGYforma, EGYszer, KÜ, PAUSE, a	
EGYszer	MI, a, egy	
egy	DA, ESZT, ORszág, ÓR, Öreg	

Király	PAUSE, STOP, SZERet, a, fi	
és	Három, MEG, két	
Három	EGYforma, LEány, ORszág, szép	
szép	LEány, volt	
LEány	a, om, á, át	Case and possession markers of nouns
az (“the”)	AR, EM, ORszág, UD, Öreg	Noun starting with vowel
SZERet	ik, te	Verb suffixes
AD	ja, ni	Verb suffixes
nem	a, is	Noun suffixes
ORszág	a, om, (sem), át	
sem	(de), volt, várt	Verb after negation
MONDta	EGYszer, a	
LEG	(I), job, kis, szebb	Superlative
SZER	e, etsz	Verb person
FEL	el, elj	
ÉDes	APám, LEány	Noun in addressing
el	te, telt	
MEG (multi-functional prefix)	es, fog, lát, tet	Verb stem after prefix

LEFT CATS 6 edited; selectively		Interpretation
MONDta, volt	EGYszer	Verb (Past)
az, egy	Öreg	Articles
a, széd, Öreg	Király	
a, mert, nincs, és	Három	Predecessors of noun group
Három, a, szép, ÉDes	LEány	Noun group
EGYszer, KÍrály, KÉRdezte, LEány, MONDta, ORszág, ban, dult, ek, ik, ja, lamb, mind, mint, nak, nem, rá, szett, sírt, ta, te, volt, úgy	a	Various words and endings requiring definite article; nouns among them
HOGY, en, hogy, ki, még	az	Same as previous
KÍrály, -ek	SZERet	Noun
SZERet, el, et, hát, szélsz	te	Past tense
lett, te	VOLna “would”	Verb Conditional
BÚZ, LEány, ORszág, ÓR	át	Object Case/Accusative
hez, nak	AD	Dative/Allative before a verb
Három, az, egy, szebb	ORszág	Noun group
Három, volt	EGYforma	

SZERet, ebb, mely, sebb	ik	A mixed-up cat
LEány, ORszág, var	om	
JÁR, TISZ, fog, lát, áz	ta	Past Tense verb (predominately)
KIcsi, a	KIrálykisasszony	

The first of the following two lines from **LEFT CATS 6** contains **HÁrom** (“three”) as a CAT, but the second has **HÁrom** in the domain

a, mert, nincs, és	HÁrom	Predecessors of noun group
HÁrom, a, szép, ÉDes	LEány	Noun group

Since **LEány** (“girl”) is a noun, another high level pattern solidifies:

Predecessor of noun group—Noun group—Noun—CASE/POSSESSION

As far as the extracted GRAMMAR is concerned, it has no use until it comes to speech generation, which could be the subject of the next part. Obviously, to be applied to speech generation, **each generator must be tagged by all CATS**. This seems like an extraordinary requirement to natural memory (computers will take anything). But in chemistry, remarkably, it is not only natural but absolutely necessary for the chemists in order to **talk** to each other about chemical matters.

Each chemical structure can be described as a list of all its “tags,” meaningful fragments, individual atoms, and their connections in such a way that the entire structure could be reconstructed from its **linear** description. The grammar of such linear descriptions of non-linear 3D-structures is called chemical nomenclature, and it is indeed a grammar of an artificial language used every day by chemists. More about it in any textbook of organic chemistry and in [4].

EXAMPLE. The chemical name of common aspirin is acetylsalicylic acid, which is a kind of old chemical slang, not quite grammatical. Nevertheless, it tags aspirin as containing benzene ring, and tags it time and time again as an acid, as

an ester of acetic acid and a phenol, and as something containing two adjacent appendages to the benzene ring. List only the tags—*aspirin's CATS*—to a chemist and the reply will be “*aspirin.*”

I do not believe that a simulation of robot-child on simplistic “chemical” principles, using regular consecutive computers, is a gratifying occupation, although it is possible. Nature is inherently parallel, but not in the sense of parallel computing as simultaneous execution of multiple tasks within a single problem. Neither individuals nor governments are good at that. I understand parallelism as translation of **random or partially ordered** collisions into communication. I regard the elementary acts of analysis and extraction as binary encounters of quasi-molecules: small linear sequences of sounds, syllables, morphemes, words, and blocks recognize each other and negotiate the outcome of the “collision:” deal or no deal. The outcome is recorded.

Figure 1 illustrates the formation of two-level CATS by copy eliminations. Segments of different color correspond letters in the **Rules** of input processing. One of two black segments is always eliminated. The other becomes a domain of a CAT. The circles do not need to be either correct or even closed.

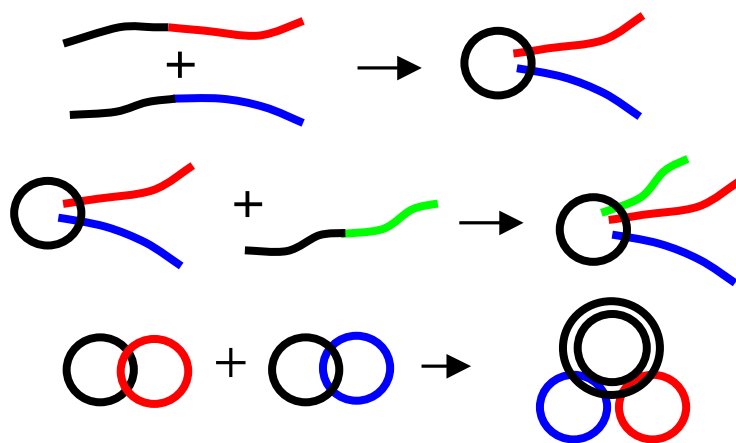


Figure 1: CATS formation in terms of linear segments

As a preview of the next phase of exploration, I will give here only one, rather weak, illustration of a possible principle of speech generation. At this point it makes little

sense because utterance starts with thought, but we do not have any settled unified approach to semantics.

Suppose we have the following content with atomic ideas:

{Király Öreg szeret só} = {king old love salt}

We do not know how the generators are connected in the thought. Regardless of the probabilities of the generators and bonds between them (which we may never know), let us retrieve all relevant lines from BONDS and CATS:

2-a;2-Öreg;	Király “king”	PAUSE; STOP; SZERet; a;
az; egy;	Öreg “old”	2-Király;
EMbere k ; KÍrály;	SZERet “love”	ik ; (3 rd person plural definite) te ; (2 nd person singular definite)
2-a;	sót “salt” (object)	2-PAUSE;
	Öreg_Király “old king”	
	a_sót “salt” “definite object”	

Although we do not know what the thought is, we could develop a set of rules for semantics. For example, **old** refers only to **king** and nothing else, but **king**, **salt**, and **love** form a **triangle**: salt is the object of king’s desire.

Intuitively, I feel that the semantic relations can be represented by a kind of triangulation in a way similar to the way speech is represented by the squashed triangles of triplets, but I cannot substantiate this idea at this point. I hope to explore this central problem elsewhere.

Figure 2 decorates the black semantic relations of the thought by red linear “comments” of the grammar taken from the above lines.

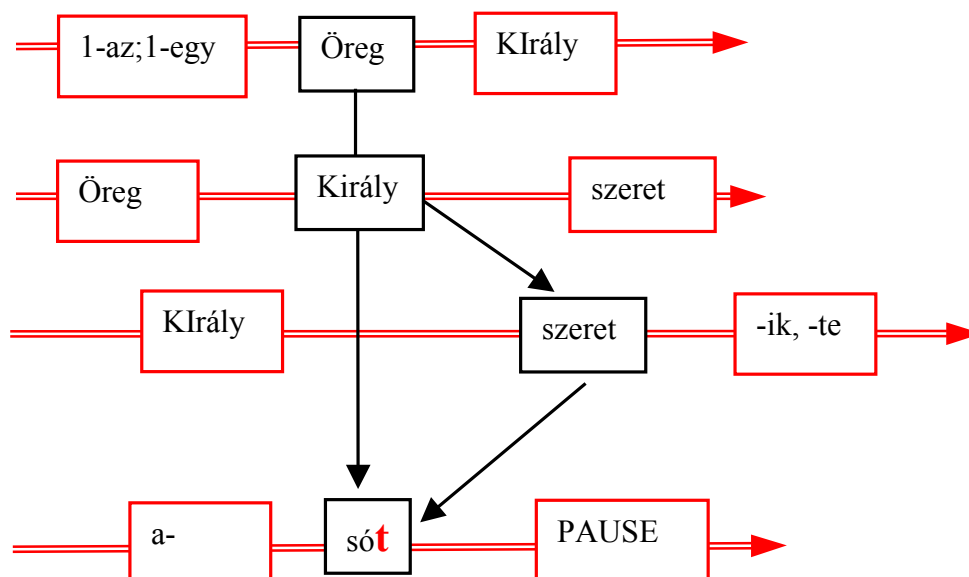


Figure 2. Comments of grammar (red) to semantic relations (black)

What follows from the comments (“catalysts,” as a chemist would say), is that the degree of conformity with the grammar is the highest when **Öreg (old)**, **Király (king)**, **szeret (love)**, and **–ik** (Present Tense) or **te** (Past Tense) somehow line up in this order. But **a só't** (salt, Object Case) has no definite place and can dangle anywhere. And why not if Hungarian has no fixed word order! Of course, **a só't** wedging in between **Öreg** and **Király** would create a tension in the rather strong bond. Otherwise, any position is fine, but **PAUSE** makes the end position more probable **in the context of Salt**.

The choice between **–te** and **–ik** is not decisive because of the lack of data. With a considerable stretch of rigor we can attribute the choice of **–te** to the absence of the end **–k** in **Király** because the end **–k** is a practically universal marker of plural in both nouns and—except 1st person—verbs.

EMberek; KÍrály; “people”, “king”	SZERet “love”	ik; (3 rd person plural present definite) te; (2 nd person singular past definite)
--------------------------------------	------------------	---

But the real solution must come from a unified approach to grammar and semantics. With all the liberties taken, the final output is:

Az Öreg Király szerette a sót , which seems to me grammatical enough.
The old king loved salt.

Note the locality of the mechanism by which I came to the above output. There were never more than three generators in the focus of my attention.

Neither the last example, however, nor all the preceding tables and examples prove anything but the need of something more convincing. They point to the role of multiple repetitions of basic speech patterns during the acquisition. What can be more convincing in our times than a solid computer simulation? The following sideshow discussion addresses this problem.

DISCUSSION

It is already clear, in the very beginning of testing the concept of robot-child, that the work is going to be very cumbersome. No wonder we have big brains. Formally, it may involve the following computational steps:

1. Each syllable or word in the input is compared with the entire generator space **G** and labeled as either old or new. If it is **new**, it is filed into **G** .
2. The memory content is re-analyzed in terms of BONDS and CATS (in advanced stages of acquisition it concerns only a very small part of memory).
3. Generator space **G**, **BONDS** and **CATS** are updated, so that each generator is re-tagged by all **current** BONDS and CATS it belongs to.
4. The entire memory is updated regarding the age of entries.

5. The next input is rewritten (compacted from phonemes to morphemes) basing on the entire stored grammar. This is the same as to say that the input is **recognized**.

Even this partial description looks like a description of a social system.

Next, how are we going to use that knowledge? Suppose, we want to express a thought, which is a configuration represented by the list of generators (content) and connections (connector graph) between them. Each entry in the content and connector (comprised by a single matrix with a non-trivial diagonal), has a numerical or quasi-numerical (in terms of partially ordered set) measure.

The thought can be a configuration of generators, sometimes incompatible, as in “Is that person over there in a dark overcoat a man or a woman?” Or: “Now you see it; now you don’t.”

Each recognized generator retrieves its entire **equilibrium cloud of associations** (I am calling psychology for help) from BONDS and CATS. In other words, the configuration of the thought should be “decorated,” as in **Figure 2**, by multiple triplet quotations from memory. In the mind of a child the quotations are certainly not in the vocabulary of the English grammar.

NOTE: My insistence on the size of linear neighborhood equal to a triplet is just for the sake of simplicity. In fact, the interactions between generators can be felt at a larger distance, which, by the way, is also a fact of chemistry.

The crucial computation stage is to find the linear arrangement of generators that which has the highest probability, i.e. lowest overall energy/lowest stress/lowest deviation from the grammar. By grammar I mean nothing but the state of the evolving mind of the robot-child, with all its CATS and BONDS (I almost said DOGS: an illustration to the concept of equilibrium).

Omitting the subtleties, all this promises a large volume of boring programming and computation. As a champion of simplicity, I am the least suitable man for this hard

labor of bug squashing, number crunching, and computer whipping. If molecules and our brains do it well enough on their own, let us better do it their way.

It is not clear about the brains, but how do the molecules do it?

There is an extremely hard (i.e., time-consuming) computational task known as the protein folding problem [5], in which, theoretically, each bead on a string must be tested in a certain way regarding its interaction with all the other beads. The solution is the configuration in 3-D with minimal overall energy. This task is so unpleasant (the so called NP-problem) because the computation is consecutive while real folding is to a significant degree parallel (sounds almost like Malthus). In other words, folding is natural and fast and our computation is unnatural and takes enormous time.

We are not as fast as molecules, so how can we speak and think at all? My answer is that this is possible because our thoughts are small, our attention span is short, our memory is a far cry from a hard drive, and our knowledge is limited. We can do it because we are imperfect. In fact, protein folding problem becomes solvable if the proteins are short. But the language is so big! Right, but the protolanguage was not. The children do not speak as layers write and even presidents can speak as children.

Let us take a break, anyway.

As a non-linguist, I can afford some unwarranted leaps of imagination. Thus, knowing nothing about the topic, I can derive the peculiar Hungarian possession marker from some ancient form with two articles (or, more probably, none at all), **a** király **a** ország, “**the** king **the** land.” The second article moves to the end: **a** király országa.

Further, I can derive the Hebrew possessive form from the same ancient pattern:

סוס האיש, sus **ha**-ish, **horse the man**, **man’s horse**. The first article drops off.

I can also throw in the English variation on the theme: **the king cobra** and all the other noun modifiers, although it is not a possessive form.

A more corpulent form remains in German: **Das Pferd des Mannes**, **The** horse **of-the** man-**his**, or **the** horse **the** man-**his**, the horse of the man.

But Hungarian catches up and even overtakes in another, reversed-German style, formal possessive construct:

Az embernek a lova , the man-him the horse-his , the man's horse.

This is, probably, too much and modern Hungarian requires only whichever one article: Peter **Peter lova** (Peter's horse) or **az ember lova** (the man's horse)

There is no article in Russian, but the marker is in place and you can have it both ways:

Лошадь Пети , horse Pete-his.

Or: **Петина лошадь**, Pete-his horse, Pete's horse (note different word order)

Furthermore, I can fantasize that the fixed stress in Hungarian compensates for the wide use of the scarce possession and tense marking morphemes. The trade-off is the free word order.

In English, the marker morphemes are very scarce and the word order is not free. In Russian, with a wide variety of markers, both the word order and the stress are free.

But the simple fact that Polish, very similar to Russian and with an equally rich choice of markers, has a fixed word order, wakes me up from my sweet dreams.

This awakening gives me an opportunity to explain once more my position. I am definitely not a linguist. I present neither a theory nor a working model. It is just an abstract idea, not yet completely clear to myself, a concept that should be tested by professionals, although it originates outside linguistics from a higher abstract ground of Pattern Theory. As a chemist, however, I feel a certain hopelessness about the current algorithmic and numerical methods of computational linguistics. They take a lot of work but prove anything but the intelligence and inventiveness of the authors. The computer models do not converge to a consensus **unless you can test them** as if they were weather forecasts or at least neural networks.

I suspect that the failure or, let us hope, a long delay in developing automatic translation follows from the very idea of algorithm, The bootstrapping mind of an infant, unlike the mind of an adult, does not use anything like either statistical inference or algorithms, **although results could be the same.**

I acknowledge that I am not familiar with the theories of computability and complexity. But I am aware that the tacit prerequisite of computer science is that **almost**

anything of practical importance can be computed within the current symbolic-consecutive paradigm, the success of which is tremendous and proven. But is the success absolute? And is it a success when it takes a lot of time and comes too late? It seems to me that the problems of automatic translation or robotic communication could be the true test for some new concepts of intelligence, all the more, they are pretty closely related to the Turing test of intelligence based on **verbal communication**. This cannot be said about playing chess. To pass the strong Turing test, the computer must express itself without help.

Trying to formulate my idea in the most succinct way, I present it like this: we could possibly create realistic models of language evolution and language acquisition if we were daring enough to change horses in the middle of the stream and switch to a new type of **natural** computers working on ordered chaos, homeostasis, and competition for energy. I presented some vague and possibly not new ideas about such pattern computers in [5]. **Automatic translation with acquired grammar and lexicon** could be a possible application and a stimulus for acquiring (what's the heck), chemical and pattern-theoretical idea by young linguists.

I can reformulate the concept in the form of an answer to the question “what is natural?” **Natural is what has infancy.**

Being unable to calculate 2×2 , such computers could be capable of computing the behavior and communication between children of pre-school age, who would be ready to start learning math and physics (not sure about chemistry), foreign languages, use algorithms, and operate PC.

I am glad I will not live in such a world, but evolution does not ask for anybody's consent. Probably we already have no choice.

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Last updated March 22, 2009



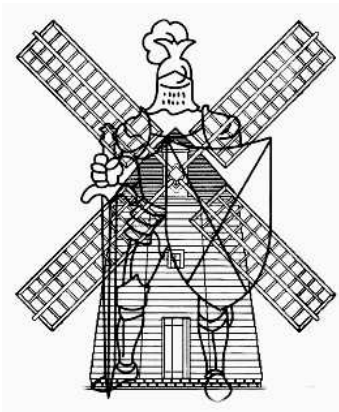
What if the words were atoms?

Yuri Tarnopolsky

IDEOGRAM : A SIMPLETON IN A COMPLEX FAMILY



2006



"What giants?" said Sancho Panza.

"Those thou seest there," answered his master, "with the long arms, and some have them nearly two leagues long."

"Look, your worship," said Sancho; "what we see there are not giants but windmills, and what seem to be their arms are the sails that turned by the wind make the millstone go."

"It is easy to see," replied Don Quixote, "that thou art not used to this business of adventures; those are giants; and if thou art afraid, away with thee out of this and betake thyself to prayer while I engage them in fierce and unequal combat."

Cervantes, *Don Quixote*. (1605)

In modern times the importance of the atomic theory is even more evident in political than in physical science.

Hegel, *Encyclopedia* , §98 (1817)

PART 1 : GIANTS AND WINDMILLS

My investigation at [complexity](#) and [simplicity](#) is gradually taking shape and purpose in my own eyes. This e-paper is an opportunity to share the still fuzzy vision.

I am interested in **evolving complex systems**: life, mind, society, language, economy, science, technology, politics, culture, ideology, art, literature, and everything that human history comprises. In particular, I am interested in the limits of our knowledge about such systems. I am not interested in a theory. I am looking for understanding.

I distinguish between knowledge and understanding. Knowledge can be generated, acquired, tested, communicated, modified, falsified, and confirmed independently by different explorers who usually come to the same or close conclusions at the same circumstances. Scientific knowledge stored in natural (physical) sciences is reproducible and lasting. We know how nature behaves and we are expanding our knowledge.

When we deal with very large physical systems, our knowledge can be incomplete and approximate, which is not such a big problem if we know the margins of incompleteness and approximation. In humanities and social sciences consensus is an exception rather than the rule. The inherent fallibility of social sciences is the main tenet of George Soros' view of the world, shaped in long, hard, and truly experimental body of work. His book *The Age of Fallibility: The Consequences of the War on Terror*, Public Affairs, NY, 2006, contains illustrations valuable regardless of his personal position.

Science itself evolves. It is a large evolving complex system. When we deal with **large evolving complex** systems (**ECS- or X-systems**), our knowledge of their behavior is incomplete because of their **size** and **complexity**. This is not a problem in itself because we usually ask questions on a limited and practical scale, unless in philosophy,

where truth matter as much or as little as in art. The main difference of X-systems, as compared to physical systems, comes from the factor of **evolution**: the phenomenon of **novelty** is something physical sciences do not observe in their objects. Novelty, however, matter a lot for a historian of science.

Our knowledge of X-systems is most complete when it is least useful, i.e., when it is about the past and, to a lesser extent, present. We even may know what is going to happen in the future, but almost never know when.

The science of complexity, as the subject of X-systems is usually denoted, was initiated and advanced either by physicists and physical chemists, or by biologists and sociologists who were applying the apparatus of physical sciences to life, society, mind, and even history and culture. Probably, the most significant result of the over half century of science of complexity is the wealth of work in the absence of consensus. I would draw an analogy with *perpetuum mobile*.

The physical sciences do not give us any exact **knowledge** of X-systems, except for about a page of general principles of thermodynamics. This small package, however, contains a true gem of knowledge: the so-called dissipative systems, some very simple and some as complex as X-systems, need a stable source of energy to sustain their size, complexity, and evolution. This energy (**free energy**, to be exact) is irreversibly dissipated into heat, with the difference retained as order.

While most living species use the sun as the ultimate source of energy, modern human civilization, in addition to the sun, relies on limited or hard to get sources of mineral fuel. Their exhaustion will unavoidably bring big changes, but when and of what kind? This question remained purely academic until recently.

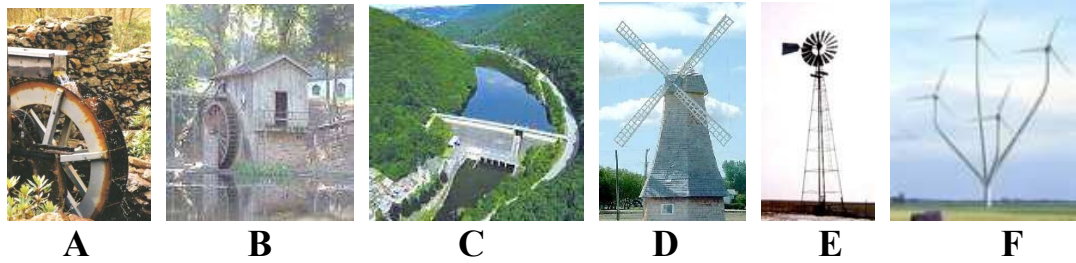


Figure 1. Evolution of waterwheel (A-C) and windmill (D-F)

A miller's windmill (**Figure 1 D-E**) is an example of a device transforming the energy of the sun—through the intermediate energy of the wind—into mechanical energy for processing grain, another form of stored solar energy needed to sustain human existence. Today this antique contraption is being resurrected and reengineered for generating electricity needed to sustain the civilization of things.

The watermill (**Figure 1 A-C**) was historically a much earlier device, but wind is capricious and omnipresent, while a creek is reliable but of a limited availability. Ultimately it, too, is driven by the sun creating the turnover of water.

I use the remarkable story of the recent windmill awakening as a pretext to pose the following question: could antique forms of social organization, for example, feudal system and monarchy, or even the tribalism, still not quite extinct in the world, be resurrected and redesigned if mineral fuel was exhausted, or for some other reason?

I ask that question—quite topical, in my opinion—to illustrate **thinking in terms of patterns**, which are much more resistant to erosion by time than particular social configurations. No wonder they are hard to kill: they are abstractions and nothing physical can touch them.

I can add another question.

The so-called war on terrorism is a war between two systems, one tribal terrorism and the other the powerful American Republic. Theoretically, the most powerful one should win.

But why is it on defense—if only temporarily—rather than in a victorious sweep it has proved to be capable of? Thinking in such terms, just from the considerations of symmetry, one may conclude that there are some very ancient and weak components in the American social system or its subsystems. Conversely, there are strong sides of tribal society capable of launching suicidal bombing on unprecedented scale.

Taking another angle, politics is always tribal and sometimes even suicidal, to which *One Party Country* by Tom Hamburger and Peter Wallsten (2006) and the midterm elections of 2006 provide scores of illustrations.

The years of the Republican Revolution remind me descriptions of carefully calculated multi-step chemical syntheses. The Republican chemists who saw the inherited (initial) and the desired (final) situation designed the step-by-step process like chemists from Pfizer or Merck, drawing a chain of small transitions from the starting reagents to the final profitable product seen in imagination.

Furthermore, modern democratic political and social institutions, such as governments of big nations, are large evolving complex systems, too, with a lot of order maintained against a lot of chaos, and they need a constant supply of energy in the form of tax revenue and donations.

In **Figure 2** I equipped the two seats of power, US Capitol and Russian Kremlin, with devices for extracting the necessary energy from wind, the inexhaustible (at least in thousand years) source of energy. The Eiffel Tower needs just a touch to become a windmill, but it is not a seat of power.

An interesting although less timely question is how much the political system could change on the supply of energy independent of geopolitical factors. This question itself leads to the next: is it possible to have some understanding of whether we can look for scientific (i.e., based on approximate consensus) answers to such questions.

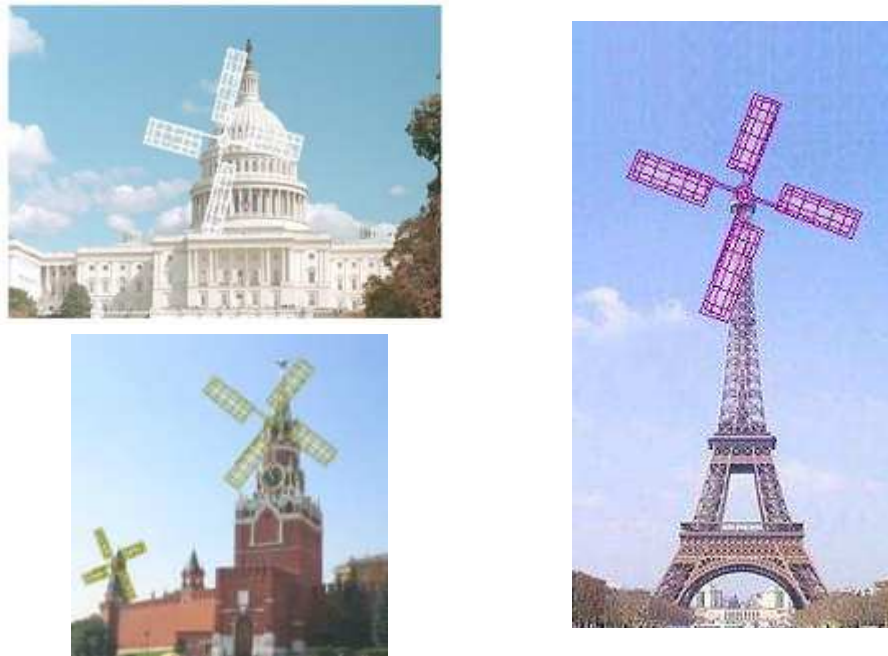


Figure 2. A vision of tax-free governments

I choose “windmill” to be an **ideogram**, i.e., in this case a label for a pattern of a device for extracting energy from long lasting source. I prefer it for its simplicity, but it can serve as a label, a **brand trademark** for the main condition of any X-system: they feed on energy convertible into work (free energy), and they need a lot of it.



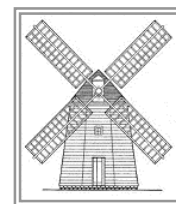
The reason why I do not use the term **pattern** is because it is already used in Pattern Theory (Ulf Grenander) in an exactly defined meaning, while I avoid exact definitions and statements. Counting on understanding rather than knowledge, I tend to recur to the subtle and indirect tools by which art commonly conveys its message to little prepared public. Thus, I believe that the series of photos in **Figure 1** do not even need any caption to convey the message. They speak for themselves.

In the language of Pattern Theory ideogram is a simple configuration chosen as a template of a pattern.

I see ideograms as symbols for universal patterns of building blocks, stratagems, and tactical tricks by which X-systems keep evolving in size and complexity.

Very approximately—to turn to original work of Ulf Grenander would be the best—the potato shape is a pattern, while individual shapes are configurations. To describe the potato shape pattern, we choose a typical potato contour as a template and define the pattern as the template and all its deformations that preserve the potato shape. In case of potato and many other visual images the deformations can be expressed mathematically in terms of group theory. In the case of ideogram we have to drag it through various X-systems, which I doubt can—or should—be expressed through equations. At the level of understanding, however, we can probably do well enough without rigor.

Back to “windmill.” In a sense, all life, and the kingdom of plants in particular, is a system that extracts energy from the inexhaustible source of solar radiation. Plants are all “windmills” in the above sense. In **Figure 1F** we can even see how the wind turbine borrows the architecture from a tree. But



there is a radical difference between the windmill and life: the windmill is a thing and life is a system. Energy and materials must be spent on making a windmill, but after that only minor maintenance is needed. The windmill is a **solid thing** with some degrees of freedom. Life is a **steady state** of flux: it needs a constant inflow of energy.

If there is no wind, the windmill can quietly wait for a long time and then resume its only slightly less monotonous existence. If there is no light for a long time, the plants will die. There are various microorganisms that never see light but generate energy from chemical bonds of their substrate. We do the same, obtaining our energy from chemical bonds of the food and oxygen, which puts us under the same pattern as mushrooms (fungi, now regarded as a separate kingdom of life) and some plants that lost the ability to utilize light. This is a very intriguing and relatively underdeveloped topic, which I regretfully have to abandon.

I prefer the windmill to photosynthesis as an ideogram because the latter is **complex** and invisible with the naked eye, while the unpretentious windmill can be seen in all its intimate **simplicity**. Diminished by the threatening complexity of the world, we could benefit from a large type book with pictures to start growing up.

We can see dramatic changes in art and culture over the last century, but what do they mean and where do they lead? We begin to see the repeating alternation of social and political patterns in modern history, but is there any kind of explanation why and when they change and what is their taxonomy? Those are examples of problems I am trying to understand without expectation of any scientific knowledge.

By understanding I mean the ability to discuss such questions in a kind of lingua franca. We understand something when we can share our understanding with somebody in common language and terminology and get the proof of understanding. This process is nothing but the traditional method of teaching and learning by communicating a doctrine, receiving the feedback by asking test questions, giving another round of explanation, and so on until equilibrium.

The multiple choice exam is an imperfect but expedient method of getting the feedback, while a live discussion in a narrow circle of scientists was the decisive way of creating modern physics and chemistry. Starting with molecular biology, however, science acquired the postmodern competitive pragmatism and protective caution. Times have changed and any idea got a price tag.

The difference between knowledge and understanding is best of all illustrated by the fact that we can understand false, fantastic, and ridiculous doctrines, while knowledge, ideally, is either testable or has testable limits. Both knowledge and understanding can be imperfect.

Understanding means a way to consensual knowledge, and if the exact knowledge is impossible, then to a knowledge about its limits and predictive ability. Understanding is

inherently dependent on the language: it is the matter of common language. Ideogram can play the same role as Chinese characters that ensure mutual understanding by speakers of mutually incomprehensible dialects. That was where I got the idea.

Since Aristotle, the traditional way of science has been analysis of a complex object in terms of its simpler parts and features. The synthesis consists in an arrangement of components in a spatial and temporal order.

A complementary way, which is neither analytical nor synthetic, goes from universal patterns to particular configurations. As a scientific method it is hopeless because in science patterns are derived from configurations and configurations from observed images, but it gives a holistic view of the world to be understood. Moreover, it makes possible invention of new configurations (a new kind of potato) and even pattern (genetically engineered fish-and-chips).

Thinking about all that as a chemist, I saw since long a big difference between the way the world was perceived by physicists and chemists. Physicists operate in the realm of continuous values, with the exception of quantum objects, while chemists deal with individual discrete structures. Thus, energy, temperature, and velocity can take any values, while graphs, i.e., combinations of points and lines regardless of distance and angle, do not form a continuous set and do not have any single natural way of ordering similar to the integers, time, or space.

We enter a mixed atmosphere in the physics of elementary particles. The quantum physics, however, deals with statistical ensembles, while there are no statistical ensembles of Shakespeares, Hitlers, or the USAs on November, 2006. There are no ensembles of French Revolutions and Collapses of Soviet Empires, either. All the wars, revolutions, and collapses do not form any ensemble because the numbers are small (hundreds) and the times are different. Yet there could be some way to **understand** revolutions and collapses, i.e., develop a temporary consensus of how to talk about them. Numerous—but not too numerous—attempts have been made.

The difference between the sciences today is as relative and diffused as never before. There is only one science and the habits of segregation stay on the way of understanding. My intent at spirospero.net , therefore, is to explain and illustrate the chemical vision of the world as a contribution to universal understanding.

Over a quarter century ago, one of my initial motivations to look at the world with chemical eyes was my inability to find a common language with an exceptionally intelligent theoretical physicist who could make any complex topic of physics understandable to me, but I could not explain why I saw big gaps in a physical approach to life and society. Physics was structure-blind and I was tongue-tied.

The new, decisive, and radical step toward developing an abstract mathematical structural vision of the world—a chemical vision of the world outside chemistry—was made by Ulf Grenander in Pattern Theory, to which I have already referred many times. Comprising both continuous and discontinuous deformations of configurations, Pattern Theory bridges the physical and structural aspects of the world in the most abstract and universal way.

I see my role as a freelance explorer of giants and monsters, prodding them with the purpose of proving that they are just windmills, what Don Quixote might have done after reading *Don Quixote*.

I have also another, purely quixotic, idea. The complexity of modern science puts a high barrier on the way toward mass education. I believe that science could be taught in a new way, as **science of everything**, with subsequent specialization along the way. Thus, my seven year old granddaughter studied rainforest at school. In principle, this subject involves all sciences and even politics and is a good syncretic start for a synthetic science of everything. The study of science, however, never becomes synthetic along the way and splits into subjects that, all but one chosen, could only be touched upon the surface, with the substance too difficult and boring for most students, especially, in our hedonistic culture of hurry and waste. The unity of the world is lost.

PART 2. STAIRS AND RAMPS

In Russia I became allergic to Marxism, forcefully fed by it all my life. In America finding a lot of reverence toward Karl Marx initially jarred me. Some components of Marxist indoctrination, however, became ingrained in my mentality; among them class structure and social justice—probably because they were not the monopoly of Marxism.

While clearly seeing a great expanse of inequality in America, I was unsure about the class structure of the country. Such often used terms as middle class and upper middle class seem to float in the air, cloudlike, while the lower class foundation and the upper class roof of the social edifice appeared to be made of a different, heavier and more dense material, constantly in public view, but theoretically inconspicuous. The very first look into American view of the problem told me that the consensus regarding class structure was nonexistent. I saw that as an opportunity to apply, finally, my new mental gadget, [ideograms](#), to the problem within the framework of the strictly individual project **a chemist's view of the world**, to which the notion of consensus did not apply. The problem certainly looked to me as a giant, and I had to show that it was a windmill.

In this section I give another illustration of what I understand as:

Ideogram: a combinatorial element, pattern, building block, or an abstract feature of X-systems represented (labeled) by its simplest or most common embodiment.

For an expanding collection of ideograms, see [complexity](#) and [Essay 47. The War](#), where I use **surface tension** as an ideogram. Essays in simplicity contain many examples of distant parallels that can serve as seeds of ideograms. Thus, [Essay 13. On](#)

[Numbers](#) applies the mathematical concept of partially ordered set to Confucian ethics.

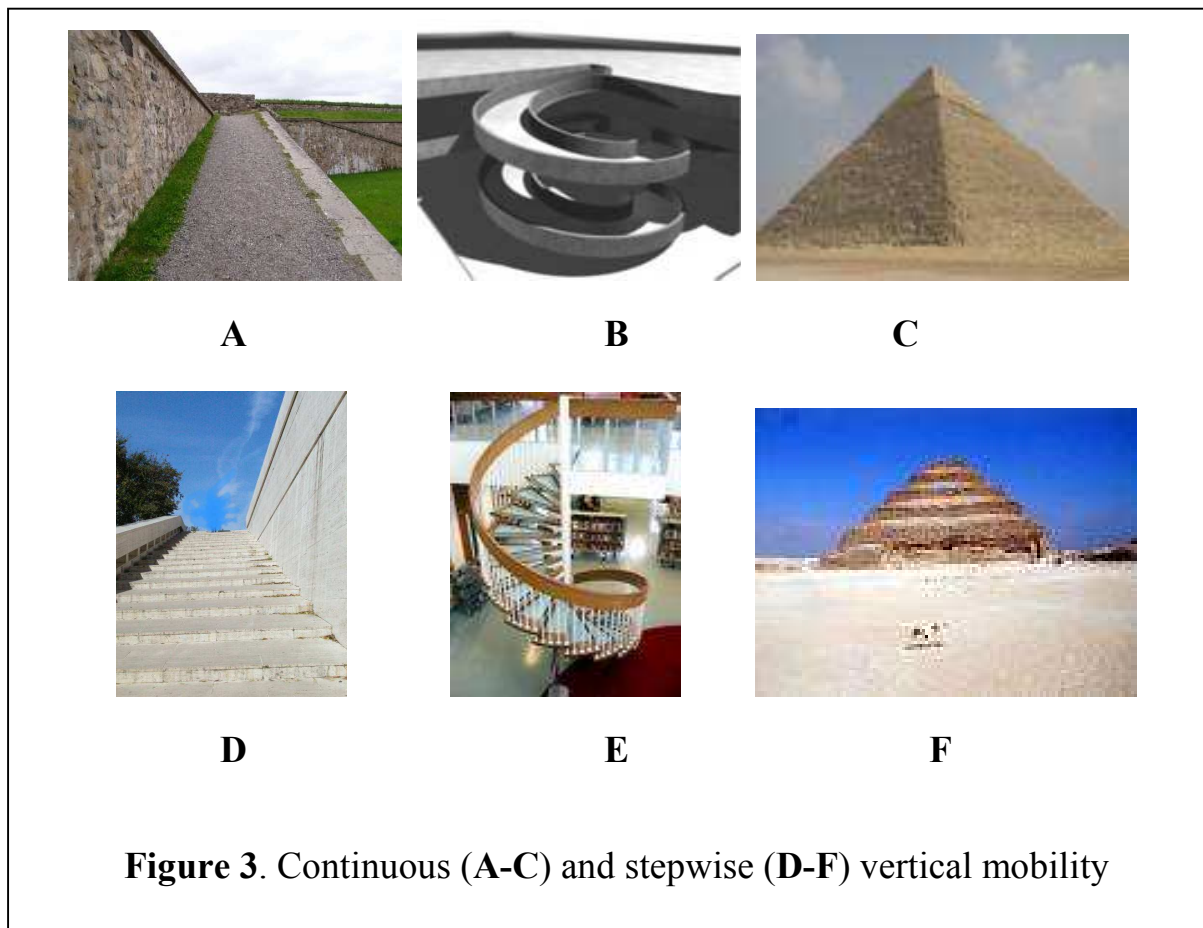
[Essay 14. On Taking Temperature with a Clock](#) deals with measuring temperature of music, [Essay 38. On Football](#) compares World Soccer Cup and American criminal justice.

The very purpose of the notion of ideogram is to use simpler objects as templates for more complex ones.

This is another example of ideogram:

Stairs: an ideogram of an evolutionary sequence of **discrete** structures of increasing complexity emerging on the **continuous** increasing supply of energy.

Figure 3 compares two types of rising structures: continuous (ramp) and discrete (steps).



That class structure can be represented by any stepped structure has been quite obvious. **Figure 4** show two out of many variations on the theme.

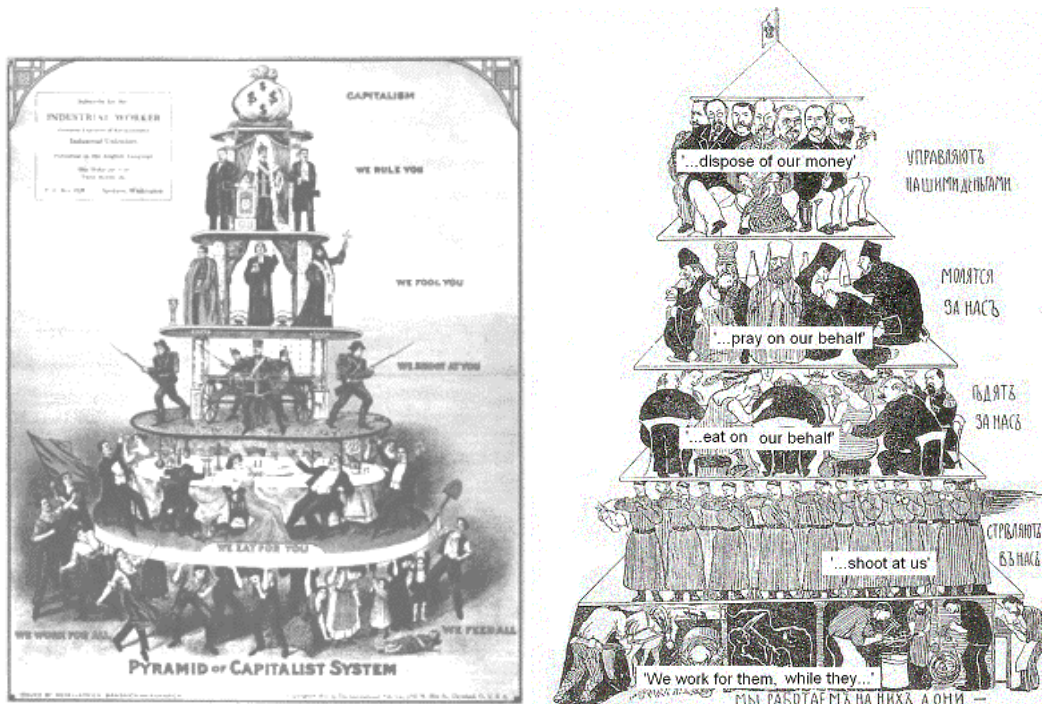
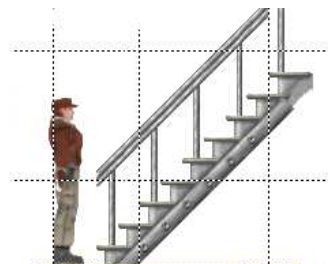


Figure 4. Old cartoons of Pyramid of Capitalist System (A) and Russian Social Structure (B). The layers are labeled, bottom to top: **(A)** “we work for all” (left), “we feed all” (right); “we eat for you;” “we shoot at you;” “we fool you;” “we rule you;” “capitalism” [money bag]; **(B)** “We work for them while they...” “...shoot at us”; “...eat on our behalf”; “...pray on our behalf”; “...dispose of our money”.

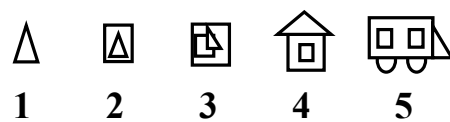
I remember a different Russian version from a textbook of history, which I could not find on the Web. The lowest and largest level was made up of peasants (“we feed you”), workers were the next (“we work for you”) and the czar and czarina were on top (“we reign over you”).

Obviously, the American society does not have the rigid social class structure in the sense of **Figure 4**. But what does it have that the economists and sociologists are so confused about?



I choose **stairs** as a version of stepped structures to label the ideogram of class structure.

The man-made things, like biological species and larger taxonomic units, do not have continuous intermediate forms. The reason for that is the discontinuous nature of structural complexity. There are no transitional forms between two different molecules. In short, structural complexity increases when the number and variety of building blocks increases. I symbolically denote a series of increasingly complex objects as the sequence:



In **Figure 5A** I arrange five sources of electrical current in order of increasing power, symbolized by pictures of small battery, car battery, ungrounded wall outlet, grounded wall outlet, and industrial switch.

While the scale of increasing current power (resource) is continuous, the complexity of man-made devices is discrete: it has no intermediate forms. Thus, there is no **common** intermediate form between a battery and a rechargeable battery (accumulator), battery and a residential current source, etc.

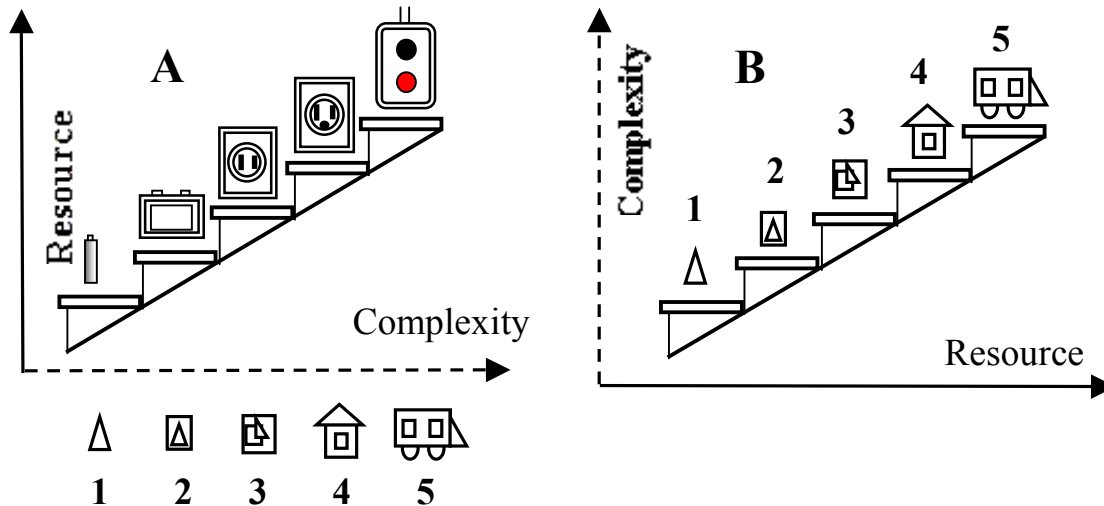


Figure 5. Complexity versus resource

Figure 5B generalizes the relation between complexity and a continuous property, which should not be perceived as a law of nature or any function, either continuous, or defined over a continuous argument, or both. I can only hypothesize—referring to George Soros as a witness—that in the realm of evolving complex systems (X-systems) we should not expect anything exact and definitive. To all arguments of George Soros in *The Age of Fallibility* I add one, in my opinion, most important: **novelty**, which by definition cannot be fully (or not at all? an intriguing question!) anticipated.

The answer to the question how we can develop any knowledge without numerical values is: we can very frequently, if not always, compare any two objects and determine which of them has **more** of some property than the other.

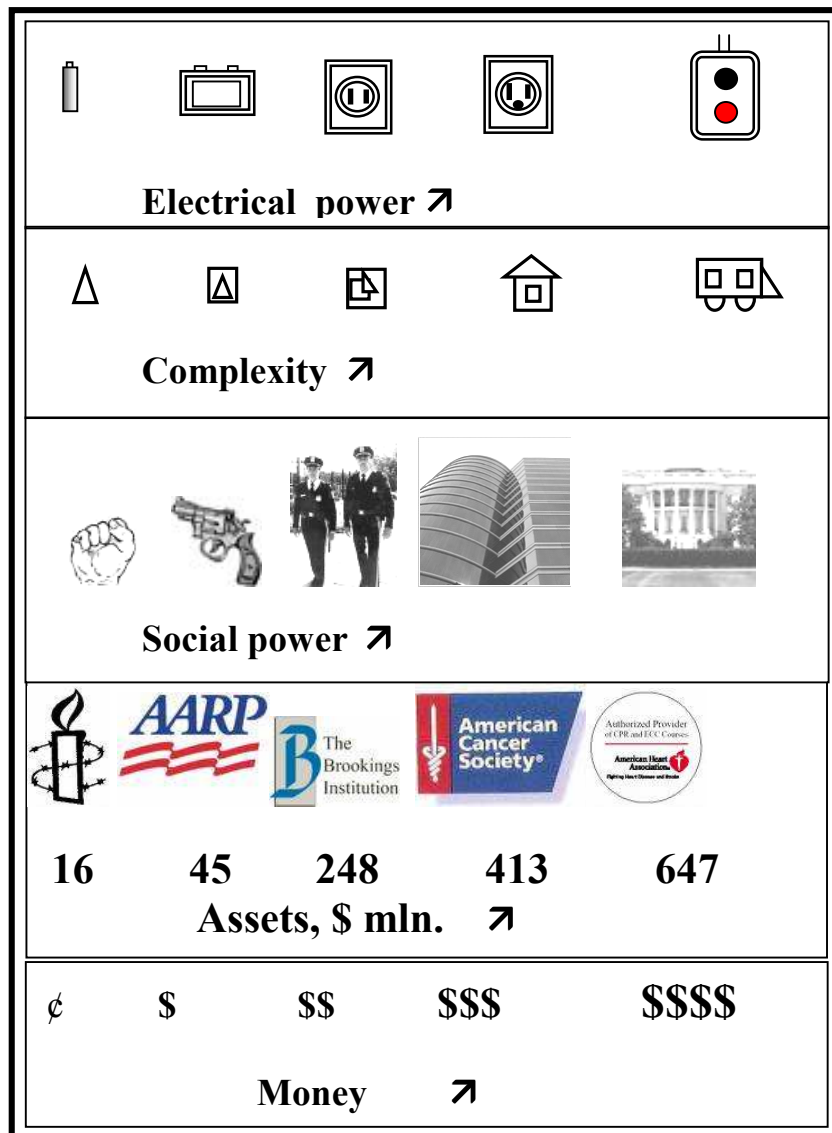


Figure 6. Resource, complexity, and system.
Linear presentation

I do not know how we can generalize structural complexity to fit a universal measure (I believe we cannot), but I know how we can generalize what I call “resource”: as energy or money. The latter is a universal systemic currency for social systems and their impact. Biological systems have their own money in the form of ATP (adenosine triphosphate).

Since we are dealing with systems, by energy I mean the energy needed to create a system and to maintain it. This is true about subsystems, even if they are “dead.” Without maintenance even Egyptian pyramids will disappear in some distant future. We deny maintenance to our computer—and scores of other things that serve us—by discarding it. We typically cannot deny maintenance to our body, dwelling, and place of work, however. Some systems, like economy, release part of the consumed energy as the production.

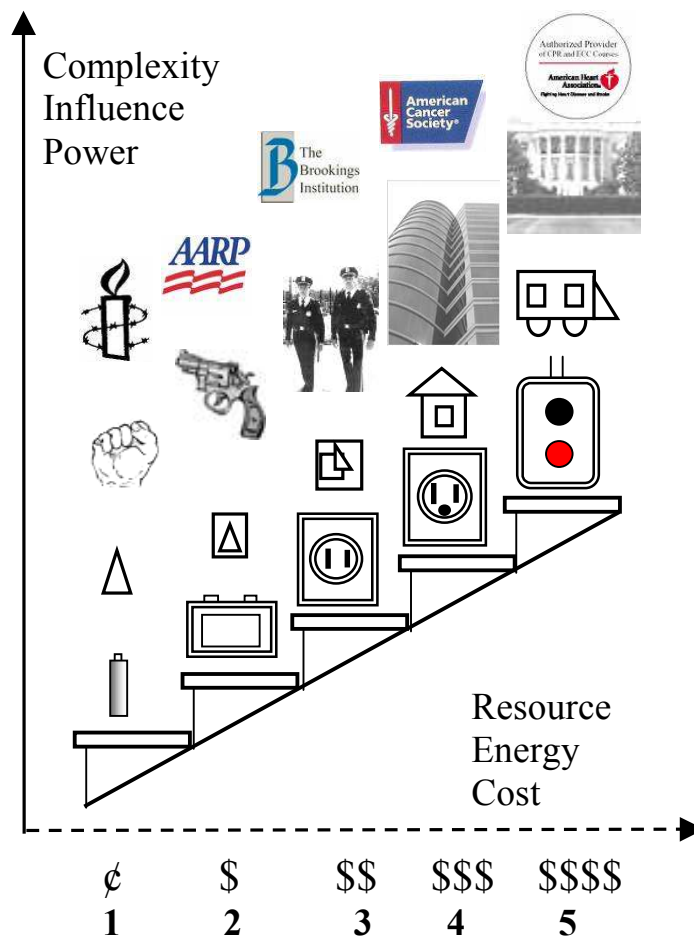


Figure 7. The stairs of power

Figure 6 gives more examples of stepwise increase of complexity and available power: fist, gun, armed group, corporation, and White House, as well as five American non-profit organizations: Amnesty International, American Association of Retired Persons

(AARP), The Brookings Institution, and American Heart Association, in order of their cost or budget (source: [Capital Research Center](#)).

Figure 7 illustrates the relation between complex systems and their common resource. It also shows that the power of a system, i.e., its ability to function in a larger system, depends on its complexity and the latter depends on the original resource. Figures 6 and 7 illustrate the great range of power.

A subsystem of an X-system is, therefore, a transponder of a resource into usable and dissipated forms. Power is the ability to provide and **allocate** the resource. Thus, a corporation or an individual who donates money to a non-profit organization (or pays to a hired killer) provides the resource and trusts the recipient with its allocation.

What does it mean to allocate the resource? A chemist imagines the final result of an experiment, which is **always** possible in chemistry because of its closed generator space (i.e., the atomistic Periodical System), and moves toward it with a significant expectation of success, employing the enormous and ever growing chemical knowledge. A failure often leads to a **new** knowledge. Usually there are many possible ways to a goal, and if one ends up in a blind alley, another may bring more luck.

A politician can see the final goal, but the goal can be very schematic and the knowledge illusory. A businessman is in a better position because of the available body of knowledge, which does not guarantee a success. But the political knowledge in our impetuous time is more illusory than anything else.

Nevertheless, many politicians are sober and realistic people. They understand that the more ambitious the goal, the more time will it take to reach it. Meanwhile, the politician can achieve a smaller, but more attainable and more selfish goal.

I have neither qualification nor intent to go any deeper in this subject. All I want is to express the idea of the **discrepancy** between the **continuity** of resource and the **stepwise** evolution of man-made systems.

Next I will try to encroach upon a completely alien to me territory of the actual class structure in modern capitalist society.

In **Figure 8** only the abstract complexity and resource are left.

The chemical picture of the world requires me to modify the design of the social stairs by adding a transition barrier from one state to the next—a universal property of every change and one of the few main tenets of chemistry. Very approximately, I see it as the one-time additional quantity of resource (initial investment) needed to create a system of a higher complexity, which will, hopefully, sustain itself.

I wish to emphasize that all my judgment regarding economics and finances (as well as numerous other subjects) is strictly amateurish and generously augmented with creative ignorance.

What follows from the above view of the problem is the **illusory character of a classless** (in economical sense) society. One does not climb the small numerous stairs, a dollar a time, to the next floor. To put it differently, here is no social ramp to the top, although, as biographies of some future billionaires testify, a kind of a ramp leads to the first step. To ascend further, one has to enter an elevator for a fee, **Figure 8**.

The limited character of available at any moment resources changes the simplistic relation between complexity of the goal and the resource. The higher one rises, the higher the elevator fee, **Figure 9**.

Figure 8, however, misses the most important property of the distribution of wealth and, probably, all specifically human values: the higher, the more rare. This class of distributions is known as **power law** and under various names depending on the area of application. Wealth in capitalist societies is distributed along **Pareto distribution**.

For our purpose we can interpret the distribution as in **Figure 9**: each next step of the complexity ladder is higher than the previous one. This does not directly follow from the Pareto distribution, but, probably, explains it. The common perception of life is that the beginning is difficult and the top is hard to reach. As far as the distance between the first and the last steps, it seems like a ramp. **Figure 9** metaphorically represents this illusion of the beginners, most of which will end up in the middle, clinging on to what they see as the slippery ramp.

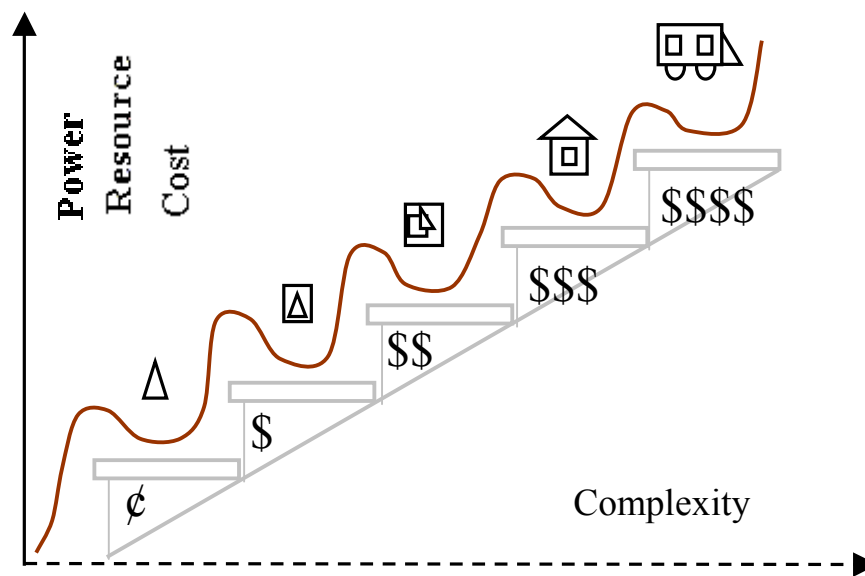


Figure 8. The chemical view of vertical mobility. **The stable positions are local minimums of cost.**

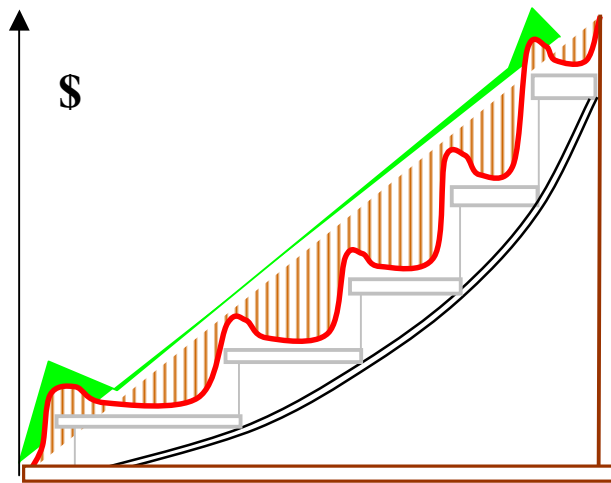


Figure 9. Increasing price of power and complexity

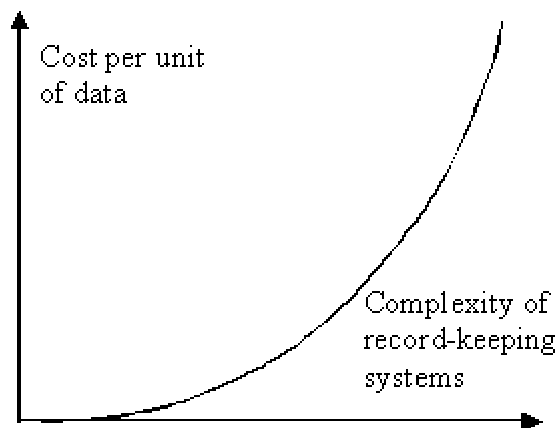


Figure 10. Cost of complexity

A casual illustration of the cost of complexity is given in **Figure 10** borrowed from: [Eljas Orrman, Structural Complexity of Electronic Records as a Factor Guiding Decisions on Permanent Retention](#). The paper deals with the problem of costs and benefits in archival storage of electronic data records. The author does not specify what complexity of a record means and simply states that “The more material

with a very complex structural form is taken into permanent/long-term preservation, the faster will the cumulative costs grow.”

I believe that complexity of modern society and its documentation is one of the major perils of democracy. The US Tax Code or congressional appropriation documents

unreadable because of their size are best examples of complexity for which **mad** or **insane** seem to be exact scientific terms and **Byzantine** too far off. This is one side of the problem. The other side is that there is no reason to expect the understanding of extremely complex problems from the elected officials, candiadtes, and the voters with the ever pressing election needs. Two years between American elections is to short a term to understand the problem and long enough to lose the control over fast pacing events.

I am going to add another example because of its intense eloquence.

Source: [Steve Burbeck. Complexity and the Evolution of Computing: Biological Principles for Managing Evolving Systems \(2004\).](#)

Complexity in the digital world is beyond our control....

Computing systems are seldom *designed* these days, they *evolve* and as they do so they become ever more Byzantine and complex. ...

Civil engineers who create steel bridges have a saying that "rust never sleeps." The comparable maxim in computing ought to be that "complexity never sleeps." And, once complexity is out of control, it takes control. Computing professionals work tirelessly to reduce complexity but all too often their efforts actually exacerbate it because the already complex systems are far beyond our comprehension. ...

IT professionals expend substantial resources detecting and cleaning virus and worm infections, patching machines, modifying firewalls, updating virus detection software, updating spam filters, and the like. ...

CONCLUSION

My investigation of class structure in America should not be taken too seriously. My main intent was to add another couple of examples of ideogram as a tool of understanding the world which is commensurable with our lives and observable directly, without either telescope or microscope. The **stairs** are a simple thing, Dopey among the Seven Dwarfs. Widely used as a metaphor, it labels, however, an important pattern of many not completely understood X-systems and is chosen exactly because of its simplicity and observability. So is **windmill**.



I have omitted here many important points and references. More than half-seriously, I believe that there is no use of a complexity treatise which is more complex than complexity itself.

The Marxist indoctrination did not make me a Marxist, but it imparted on me a lasting interest in Hegel, who was regarded, along Lenin, as one of three sources of Marxism.

I conclude this essay with a wonderful ideogram Hegel used for the inherent discontinuity of devolution: knotted rope (“knotted line”).

This process of measure, which appears alternately as a mere change in quantity, and then as a sudden revulsion of quantity into quality, may be envisaged under the figure of a nodal (knotted) line. Such lines we find in Nature under a variety of forms. (Hegel, *Encyclopedia*, §109)

Here it is:



[Main page](#)

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Do Pirahã speak Nean?

Yuri Tarnopolsky

The war of words is a metaphor that should be taken literally in linguistics.

In this essay I am omitting the history of the long war between the formal linguistics of Noam Chomsky and his critics because the linguists know the story and the non-linguists can turn to the well written article in *The New Yorker*: ***The Interpreter*** by John Colapinto. The war remains as unfinished as the Iraq war, but the general state of things is more or less clear: the Gullivers lose to the Lilliputs.

The article in *The New Yorker* is an excellent piece of journalism. It can be complemented by many available on the web professional materials googlable as: **“Dan Everett” Piraha OR Pirahã**. I have no say in a professional linguistic discussion, but my point of view may be of interest for the seekers of new ideas.

John Colapinto actually traveled to the Pirahã tribe in Amazonia together with Dan Everett, a linguist and an unordinary personality, who is an unrivaled speaker of the exotic language of the tribe.

John Colapinto writes (p.130):

When I asked Everett if the Pirahã could say, in their language, "I saw the dog that was down by the river get bitten by a snake," he said, "No. They would have to say, "I saw the dog. The dog was at the beach. A snake bit the dog."

I recognize in Everett's transposition the language that I called Nean in my web publications:

1. [Pattern Theory and "Poverty of Stimulus" argument in linguistics](#) (PoS)
2. [Tikki Tikki Tembo: The Chemistry of Protolanguage](#) (Tikki)

and others at [complexity](#).

I am a chemist and not a linguist, although I am superficially familiar with the basic structure of several very different languages. My interest in languages is part of a larger program "a chemist's view of the world" pursued on my [website](#).

I see chemistry as one of the two most romantic sciences; linguistics is the other one. There are many parallels between them, which I explore at my site. Thus, chemistry uses an artificial language that compresses the rich three-dimensional world of chemical structures into a strictly linear sequence of symbols, exactly as our language does when we describe an elephant or the global warming. "The language of DNA" is not a metaphor, but a standard term in molecular biology. Mark Baker, an eminent linguist, entitled his book "The Atoms of Language."

Here is just one example, which I never used before. One of the starting assumptions of the entire theory of Noam Chomsky about universal grammar was the ability of children to construct correct sentences never heard or corrected before (the so-called poverty of stimulus argument). An average chemist during his or her life brings to existence large numbers of chemical substances that never existed before, probably, even in the entire solar system. Each gets a unique name that serves as a photo ID: you can draw the molecule from the name and materialize it in the lab, if you wish.

I am a father of several dozens of never before known substances, but there is nothing to be proud of: anybody can do that. Does it mean that I have some innate knowledge of chemistry? Of course not. Chemistry had even denied a possibility to make some of my molecular children before I actually did it.

I and the rather happy looking and attractive Pirahã Indians, whose photos can be seen in *The New Yorker* and on the web—we all have an innate ability to understand the world and acquire skills and knowledge. If the adult Pirahã cannot learn counting, it means that they either do not need it or the teacher cannot find the right key. If I am not mistaken, some of our very distinguished citizens could not master the Internet, either. Inability to learn the new lessons of history is even more common, and for the same reasons that Dan Everett attributes to the Pirahã: “This is new stuff and they don’t do new stuff.”

Most normal people in this hemisphere are not only incapable of learning chemistry but consider it the most incomprehensible and even repulsive area of knowledge. There are plenty of other occupations, for example, making and counting money. Some of our top national leaders occasionally fail even at their supposedly innate language skills, instead relying on somber language of power—a language much more poor, color-blind, and primitive than even the language of the Pirahã.

But what is Nean? In short, it is speaking in triplets or even in doublets. “I see dog. Dog was beach. Snake bite dog.” This is a good example of Nean grammar. It does not sound good, but all first contacts between different tribes and nations started with learning a pidgin version of the other language. The study of pidgins is a separate branch of linguistics. The fact of great importance is that we understand “I see dog” and “Dog was beach,” especially, in context. It is probably obvious to any Amazonian that snakes are common on beaches. He can explain to the crooked head: “Snake was beach” or simply “snake beach! snake beach!” “There are many snakes at the beach” sounds like “snake snake beach! snake beach snake snake!”

Nean, in my view, is not exactly a language, but the primeval natural grammar. That was my first thesis of an outsider when I got interested in the origin of language some years ago.

I suggested in *PoS* and *Tikki* that Nean is a grammar of such simplicity that it could originate spontaneously by self-organization. This follows from my perception of

complex systems: any natural complex evolving system, such as life, society, culture, technology, etc., starts spontaneously as a system of minimal complexity. Then it grows, evolves, beefs up its complexity, and diverges. Only very simple things in very simple systems can happen without the input from a deity, human, or alien. A group of monkeys cannot type *Hamlet*, but they can certainly type by accident the name of Hamlet. Names like Bush and Gore are even more—and equally—probable to pop up in such experiments. No political allusion intended.

NOTE: At a closer look, to type “Bush” may require less physical energy than to type “Gore.” “Gore” takes longer jumps from key to key. But this is arguable. What matters is the approach to language as to a natural process. What takes less energy is more probable.

On the contrary, if a system is created by human mind from some existing material, it may not need simplicity. Bureaucratic systems are the best example. It has been noticed that our appliances are getting more complex and less reliable. The natural history of bureaucracy as pattern, however, also had to start with something very simple, such as just counting or policing. Moreover, counting also had to start with counting to two, further proceeding to tree, five, and ten or twelve.

In order to advance in mathematics further, you need a mathematician. The same with language: you need a speaker and a writer. But you need Demosthenes or Cicero only in a developed society. They are not expected to be good hunters in the jungle.

My second thesis was that the system consisting of the speakers and the social environment maintains the state of homeostasis, which, probably, is the case with the Pirahã tribe. There is no natural language separate from nature. Language is the device for maintaining the homeostasis of the tribe. If it evolves, it is because the homeostasis has been disturbed. If not, people can manage with what they have.

My third thesis regarding language was that we have two very different kinds of languages. One (Language1 or hypolanguage) is the language spoken today in a much

more advanced form only by some uneducated and illiterate, but otherwise completely normal, gentle, skilled, and caring people, albeit with limited experience, which we can find only in particular areas and social strata of the world, even in quite civilized countries. It is also the language of children before some age and level of schooling. It is also the language of new immigrants who are not as articulate as Noam Chomsky, but their children may become one. It consists of short segments of speech, often repetitive and overlapping. It is practically free of embedding and recursion. It is simple because it is difficult. For the same reason *Hamlet* is more difficult than “Hamlet” and “Hamlet” is more difficult than “Gore.” But the cardinal fact is that we understand Language 1 and people can successfully communicate in it, up to a point.

The second language (Language 2 or hyperlanguage), that of long composite phrases with many subordinate clauses, is the result of advanced evolution. It is a bulky human artifice, like HMS Queen Mary II. It was gradually created, by trial, error, and mutation, in order to represent the growing complexity of civilization, including complex ideas and constantly shifting homeostasis. It is the language of science, literature, and bureaucracy. It has nothing to do with the origin and essence of the language that all humanity speaks, but everything to do with culture, society, economics, and maybe a desire to show off. On the negative side, it is also the truly barbaric language of the fine print and the US Tax Code—the language so alien, that we pay big money to professional translators.

With all the fuss around the Pirahã, I feel a need to find some new non-professional arguments, just to convince myself.

All Soviet college students in my time were mobilized to spend at least a month doing some agricultural work—a kind of forced labor. While doing time in the Russian countryside, I witnessed the aboriginal Russian and Ukrainian language, which used probably one percent of the grammatical resources (and sometimes 200% of the foul vocabulary for the male speakers). It was not a local dialect or slang, but the natural speech of some people of mostly older generation, sometimes almost illiterate, and born before the introduction of the comprehensive system of education that the Communists had among their undeniable achievements.

I of course do not have any examples. I remember, however, that in spite of its simplicity, the language was by no means handicapped. It was very expressive, for which there are incredibly rich lexical and morphological resources in both Russian and Ukrainian. It was in homeostasis with environment. It served its purpose and function. I understood the speakers and they understood me.

Stimulated by the story of Pirahã, I decided to look at the records of Russian folklore that could open an audio channel to the past..

There is a Russian site dedicated to Russian literature and folklore: <http://feb-web.ru/>

Here is an example of folk poetry collected in Russia in the middle of the eighteenth century by Kirsha Danilov (in my translation).

"Гой еси вы, князи и бояра	Hey, you, princes and boyars,
И могучие богатыри!	And mighty heroes!
Все вы в Киеве переженены,	You are all married in Kiev,
Только я, Владимир-князь, холост хожу,	Only I, prince Valdimir, remain single,
А и холост я хожу, неженат гуляю,	I remain single, walk unwedded,
А кто мне-ка знает сопровитницу,	And who knows a mate for me,
Сопровитницу знает, красну девицу:	Knows a mate, a handsome girl:
Как бы та была девица станом статна,	Be that girl slender of figure,
Станом бы статна и умом свершна,	Slender of figure, clever in the head,
Ее белое лицо как бы белой снег,	Her white face like white snow,
И ягодицы как бы маков цвет,	The cheeks like the scarlet poppy,
А и черныя брови как соболи,	Black brows like sables,
А и ясныя очи как бы у сокола".	And the lucent eyes like the falcon's.

The only possessive pronoun is highlighted. Otherwise, there are no obvious grammatical connections between the lines. There is no embedding. The short segments are brought together by the repetitions that look like the “pre-existing condition” of haplology, which I discuss in [Tikki](#):

The lines look ready for haplology contraction:

And who knows a mate for me, Knows a mate, a handsome girl: Be the girl slender of figure, Slender of figure, clever in the head, Her white face like white snow.

They can contract into the single phrase:

And who knows a handsome girl with a slender figure, clever head, and a snow white face, who could be a mate for me?

The folklore is not what we can call natural speech. It is a one-way communication and a product of long evolution, polished by centuries. It can be seen as an intermediate step between Language 1 and Language 2.

Here is another example:

"А и ласково сонцо, ты Владимир-
князь!
Не нада мне твоя золота казна,
Не нада три ста жеребцов
И не нада могучия богатыри,
А и только пожалуй одново мне
молодца,
Как бы молода Екима Ивановича,
Которой служит Алешки Поповичу".

You are indeed a gentle sun, prince
Vladimir!
I don't need your golden treasure,
I don't need three hundred stallions,
I don't need mighty heroes,
Only give me one lad,
Like the young Ekim Ivanovich
Who works for Alesha Popovich.

In the samples of old Russian poetry, the word **которой** (**kotoroy**) is the subject pronoun **who** with a male gender ending. It can be found in the collection of Kirsha Danilov, **but it is rare**: 18 per 8000 words (0.002). In an at random selected segment of Leo Tolstoy's *Childhood*, the frequency of **kotor-** plus case and gender ending is 27 per 2512 words (0.01). Tolstoy, however, uses all other available subject pronouns and high level of recursion (still negligible as compared with the American Tax Code).

The two last lines of the above example could be put differently, in the tradition of "pre-haplology:"

Как бы молода **Екима Ивановича**,
Еким Ивановича при Алешке
Поповиче."

Like the young **Ekim Ivanovich**,
Ekim Ivanovich with/at Alesha Popovich.

Apparently, there was a lost in time person who applied haplology and invented the pronoun out of **something available for another purpose**.

My point is that the Nean grammar, in all its natural primitiveness, opens a way to further **gradual evolution** toward modern recursive language, which we, however, try to avoid in everyday communication. The dense recursivity is intended for the written language, which does not impose a heavy burden on memory. The written text keeps a large chunk of narrative fully in view.

Regarding Pirahã, the controversy comes not from its peculiarity but from the theory that was built initially on Language 2 but tried on Language 1 or 1.5.

I believe that the painful Frankensteinian story of formal linguistics, re-tailored, re-cut, and re-patched many times over (but so beneficial for scores of graduate and postgraduate students of humanities all over the world), would come to an end long ago if Noam Chomsky started with simple languages of pre-literate people instead of the non-existing infinite productivity of grammar under the pens of sophisticated writers. It looks like John Colapinto also noted that.

My prediction is that with more time the Pirahã, the immigrants from our past, who suspect the outside traders of cheating, will find a way to control their trade, probably, by letting their children learn math and Portuguese. In the immigrant families it is the children who serve as an interface between the old folks and new reality. Until then, it is just a tribe whose homeostasis has been miraculously preserved, as Dan Everett's remark in his [main paper](#) testifies: "The Pirahã are some of the brightest, pleasantest, most fun-loving people that I know."

If Russian is a language, so is Pirahã. But probably not for the reasons of the formal linguistics.

As for the formal linguistics, a similar story happened with chemistry: it was prevented for a long time from the true understanding of nature by the dogmatic theory of phlogiston, the hypothetical substance of flammability with zero or negative weight: sulfur burns and disappears because it consists of phlogiston. During the entire eighteenth

century large number of contradicting treatises had been written in order to make some sense of the theory—quite like with universal grammar—before Antoin Lavoisier knocked it off like a dead cockroach. He then lost his head in the French Revolution, but this is a different story.

Quite unexpectedly, the Pirahã story has made me appreciate the historic significance of Noam Chomsky as a public figure on the world scale. He has been keeping linguistics in the focus of public curiosity and attention. As result, the very linguistic trade today is alive, growing, and hot. Naturally, mosquitoes from the young swarm have come to bother the master and grow through the ranks on his blood. Similarly, as a stinging gadfly himself, he has been driving the pachydermous American foreign policy into the focus of world attention, although the animal was quite capable to stay there on its own. Whether he is right or wrong is of secondary importance as compared with the importance of his dogged search for truth. Can a really intelligent person be **completely** wrong?

John Colapinto got his story right. In politics follow the money, in private life *cherchez la femme*, and in linguistics listen to the horse's mouth.

SELECTED REFERENCES:

Dan Everett's main paper: <http://www.stanford.edu/class/symbsys100/everett.pdf>
or <http://ldc.upenn.edu/myl/llog/EverettPiraha.pdf>

The detailed paper of Andrew Nevins, David Pesetsky, and Cilene Rodrigues, which criticizes the conclusions of Dan Everett, can be accessed through <http://ling.auf.net/lingBuzz/000411> (click on the title) or directly downloaded through <http://ling.auf.net/lingbuzz/@uESGsWZHRsRjdIx>

A sample of Piraha text: www.llc.ilstu.edu/dlevere/docs/panther.pdf

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THE RUSTY BOLTS OF COMPLEXITY

IDEOGRAMS FOR EVOLVING COMPLEX SYSTEMS

ABSTRACT

This essay continues a series of discussions (<http://spirospero.net/complexity.htm>) in which a chemist joins the debates about the **large** and **complex** world outside the narrow professional setting. It aims at **understanding** evolving complex systems (ECS- or X-systems: life, mind, society, culture, economy, language, ideology, etc.). Understanding requires transfer of information in a **language** shared with the receptor. The language must include terms for most **abstract patterns** of action and change regardless of particularities of the system. An attempt to create highly abstract **ideograms** for such patterns was made by René Thom. The problem is discussed here from the point of view of transition state in generalized chemistry. The focus of interest is the origin of the stubborn growth of complexity typical for X-systems. An aggregation through multiple weak bonds is a possible general pattern of complexification. The alternative to algorithmic complexity **pattern complexity** applies not to configurations but to their harboring configuration space. Pattern complexity grows when the space expands. Examples and toy models (ditalini pasta, “brushmobile,” rusty bolt, zipper, “wealth pump,” bow tie, and others) are used as illustrations. Pattern understanding of history is discussed.

KEYWORDS: Pattern Theory, Ulf Grenander, René Thom, Hannah Arendt, Gregory Chaitin, Stephen Wolfram, Leonard Talmy, complexity, transition state, evolving complex systems, theory of history, cliology, understanding, X-systems, stability, lability, generalized chemistry, multiple weak bonds, origin of life, origin of society, origin of life, aggregation, cognitive semantics, ideogram, iconic graph, metaphor, bow-tie structure.



“There are flows taking place within society and culture.” ...

“What seem to flow from the wider culture to the scientific activity of an individual, and back, are more easily described as *ideas*, *representations*, or *metaphors*.”

David Aubin [9A, p.6 and 7]

Introduction

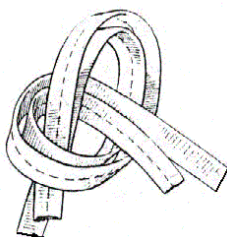
In this essay, as free-wheeling as all the [others](#) [1], I would like to offer a taste of a possible conceptual base for understanding **evolving complex systems** (X-systems: X is short for ECS) **from the point of view of a chemist**. I stop short of SECS, Spontaneously Evolving Complex Systems not out of prudishness, but because I distrust spontaneity. Examples are biosphere, life, mind, society, economy, technology, science, culture, art, media, politics, language, ideology, i.e., everything from molecules to ideas, or, in terms of outer limits, from biosphere to noosphere. Some concepts mentioned here are discussed in [1] in more detail.

Watching the development of the entire area of complexity and complex systems for at least half a century, I see no sign of consensus and not even a hint that anything like formal theory is possible. Taking to account the number of brilliant minds highly successful in their professional areas and looking at a larger world outside the laboratory, I attribute the lack of a unified **theory** of X-systems to the fact that by **theory** everybody understands what it means in a particular professional domain. The best illustration is the rift between sciences and humanities. How can we count on any consensus, regarding, for example, human history, if physicists and historians—who know about history

incomparably more than physicists—do not have a common language not only between each other but also with biologists, psychologists, artists, philosophers, etc? Instead of computer games at one end of the scale, Grand Theories of Everything at the other, and quantum intelligence somewhere in the middle, we could do better by developing a common language for the modest purpose of **understanding** what Everything is, as well as what **is** is.

This preliminary sketch, with an intent to expand on major topics in the future, ties in a loose knot the following strands. Although I am a **chemist**, my major influence for twenty-five years has been **Pattern Theory** of Ulf Grenander, which in my eyes is a **generalized chemistry**. I have been familiar with the ideas of **René Thom**, **Stephen Wolfram**, and **Gregory Chaitin** for as long. Most recently I have been impressed by some other discoveries, among which **Hannah Arendt** had the strongest impact. Having no **formal theory** of its own,

Like **computation**, chemistry between theorizing and ***faber***, man the maker, the chemical **catalysis**, the Those are the strands tied in a



chemistry borrows it from **physics**. takes an intermediate position **making**. Hannah Arendt's ***homo*** modern hero, clearly resonates with chemical maker of life on earth. knot in this essay. The knot is a

metaphor and metaphor is one of the strands of the essay, too. The knot in the center of this paragraph is an **ideogram**, which escapes a single definitive explanation. It can be interpreted as: (1) marital knot, (2) movie plot in which two characters become inseparable, (3) coincidence of two policies on some points and divergence on others, (4) military quagmire, etc. The list of interpretations is always open and the prospects of the knot of being untied, cut, or fused into a permanent connection are uncertain.

PART ONE: CHATTING

I am a chemist and the secrets of life are least of all mysterious to me. I am very much intrigued by mind and language, but most of all by understanding society and its future.

My upfront goal is to illustrate how we can discuss cabbage and kings within the same vocabulary, so that they would look like twins. My secret goal is to infect the reader with the suspicion that **chemistry is about human existence** (human condition, as Hannah Arendt [2] would say) in the widest possible sense—oops! no more a secret. The world looks very peculiar through the eyes of a chemist, whose vision is as different from that of a physicist as the vision of a bee or a dog from ours: it is adapted to see through complexity.

I am driven by a sheer intellectual curiosity because at my age I have little practical concern about the future. Yet I have also some personal reasons to be curious about the larger world.

My interest in large complex systems comes from the time when I lived in the Soviet Union, trying to understand a social system that seemed completely unnatural and doomed. Although hardly anybody saw a quick end to it, the end came soon after I had left Russia. I went to America, swearing to purge my native land out of my mind—the vows of eternal hate are as futile as the vows of eternal love.

About twenty years later, Russia, the country crucial for the fate of Europe and the West, seems to be taking a new historical turn, which I am no more interested in. Judging by daily news, the turn would qualify as a regression to Russia's tsarist past.

I am much more concerned about my new American homeland, which offered me freedom, shelter, and comfort.

I can see in the current presidency in America (2000-2008?) some shocking, however distant, similarities with what I saw in Russia. I suddenly begin to sense the historic fragility of the **present**, in spite of a however glorious **past**, facing the invisible and incomprehensible **future**, which today is as global and unmanageable as never before.

Regarding history, I am a fatalist, which means that I believe that the events have a preferred direction. The ripe apple always falls down. This may seem like a physicist's credo. But our understanding of the world is a component of the events. If I believed in equations, I would say that our understanding and expectations count in the equation of the future. But I do not believe in equations for X-systems.

In his intelligent book *In the Country of the Blind* Michael Flynn [3] imagined a practice of **cliology**, i.e. the applied science of history—with equations—which developed into a true technology, mostly of cloak-and-dagger type, of designing and shaping the future. As every landmark idea, it is valuable for questions it poses rather than for answers.

The technology of making history has been in fact evolving throughout history from the cloak and dagger to the suicide bombers and from the quill to the character assassination through TV ads. I do not share any illusions about possibility of a **theory** of history. The reason for my negativism was perfectly formulated by Hannah Arendt [2]: the historically meaningful events are those that violate statistics. I would also add: and equations. They always come as unexpected irregularities. Instead I have the following five point program to consider.

1. Since we cannot experiment with history—we can and we do, but the experiment cannot be reproduced—cliology is extremely unlikely. **Impossible** is a forbidden word anywhere except mathematics. **Infinity** is forbidden everywhere else. What we can do is to **understand** history.

2. We never know if somebody understands something unless we have some feedback. By **understanding** I mean the ability to convey a doctrine (an open system of

principles, explanations, and examples) to other people, for whom the ideas are **new**, in the **old** terms, so that they will prove their own understanding, not necessarily perfect, by passing it back to the source for the check, as well as further down the line, until it diverges or evolves into another doctrine. Understanding, therefore, requires a **common language** and involves a kind of a teacher-student relationship which **converges to a consensus**. Like a relationship between two gossipers frequently exchanging “if you know what I mean.” If understanding, according to Gregory Chaitin, means compression [4A], the proof of understanding means ability to compress and decompress in more than one way, like folding and unfolding a napkin in various ways.

For comparison, here is Ulf Grenander’s note on understanding:

We claim that we understand the pattern only if we can analyze it in terms of a given knowledge representation or, alternatively, if we can pinpoint in what respect it differs from what the representation prescribes. [5A, p. 100].

3. If we understand history up to its current moment, so that a nearest future brings a delayed test, we will be able to pass the understanding to posterity facing a more remote future than ourselves. It will be irrelevant by that time, however. In other words, our understanding of the world in the short run can be very different from that in the long run, but we never have the long enough run ahead. This contradiction is dramatically different from the post-Galilean belief in the timeless laws of nature on which all our activity in the role of *homo faber* is based.

4. Suppose we can elaborate a set of principles that govern the **preferable direction** of historical events in the short as well as in the long run. By regarding “historical” as “natural,” we will come to a version of thermodynamics, which is a very small set of universal principles about natural and man-made events. Unfortunately, thermodynamics, timeless as any good **science** should be, is silent about the short run, while history is all about the time span of at least one or two generations. We would at

best know **what** could possibly happen, but not **when**. We would know a set of alternatives but not whether it was complete.

All we can do with thermodynamics is to conclude that an earthquake in San Francisco or even the end of the world is imminent. What we need is **kinetics**, i.e., the knowledge of the **relative speed of alternative events** and how to manipulate it. Thus, in the presidential elections of 2004, in which the Republicans were much faster and nimbler than the Democrats—for which there were pervasive thermodynamic reasons—the outcome could be, theoretically, different if the campaign lasted just a couple months longer.

For more about kinetics regarding abstract systems, see [1].

The outcome of the Battle for Britain during the WWII was decided by the faster adaptability of Britain. The outcome of the competition for energy resources between the giant nations and unions (USA, EU, India, China) will depend on who adapts to the exhaustion of mineral fuel faster. The **rate** of the population growth, which seems turning toward negative [3B], is of the paramount importance for the political shape of the globe and a sustainable, however unexciting, economy. The chemical industry is possible because of the differences in the speed (the chemists call it **rate**) of the desired and the unwanted reactions, while the respectable wine industry is based on equilibrium thermodynamics and is in no big hurry: the longer the better.

The world is not flat because **kinetic barriers** warp, wrinkle, and crumple it.

5. If history **always** brings something **new** and unexpected, could our understanding of history be lasting? The property of **novelty** is intrinsically alien to any closed **theory**, but our language is quite agile at expressing **new things in old terms**, after which new terms are assigned to new things and immediately cease to be new. What we can theoretically predict is not new. By definition, the new cannot be predicted, only the different.

End of the program.

Regarding the problem of realistic understanding X-systems, I have two related hypotheses.

My first hypothesis is that **if** we can foresee the physical fate of the earth for centuries ahead—alas, there is a problem, too—we can try to project reasonably far ahead our open-minded understanding of history and its distinctive technology. More generally, **understanding lasts until the larger system that houses the system under consideration changes dramatically.** I hope that there are some limits to meaningful abstraction.

My second hypothesis is that **from a high enough level of abstraction, our understanding of an X-system will be simple.** In practical terms, the number of alternatives for the future will be very limited. At least we would not care about the next president. Alas, this makes computation, the God's manna for tenure seekers, useless, but this is not my problem.

The two hypotheses can be combined in a statement that may seem paradoxical. **In order to make predictions more accurate we need as less detail as possible.** In other words, we should step back and look at the Earth as a whole from a distance: from what Hannah Arendt [2] called **Archimedean point**. We will not see much, but we will see what is large and lasting. In practical terms, we need to develop an abstract language to talk about Everything over the Grand Canyon dividing sciences and humanities. Neither formal mathematical systems nor physics can bridge it, to which a century of debate with no consensus testifies, because **formal systems are not open to novelty.** They are designed to be timeless and this is why they are disposable and can be out of favor if a **new** formal system (paradigm shift) looks more realistic.

Chemistry, on the contrary, is an open system because it is not formal. Chemistry, like art, is a collection of old novelties, but it expands by the minute. Novelty is a recognized, however ephemeral, property of chemical compounds, see [1A, Chapter 1].

Of course, chemistry, as everything else, looks simple only from the Archimedean point.

Paradoxically, biology has a theory based on chemistry, but chemistry does not have a theory in the **common** sense, except for physical theory. It possesses a very compact, but extremely successful, set of principles involving thermodynamics and kinetics, as well as efficient methods of handling the ferocious structural complexity. Of course, reducing it to simplicity, what else? Chemistry, however, has been silent on the subject of Everything and for a good reason: the proof of the chemical pudding is always in the making, not talking. Fortunately, Pattern Theory [5] (Ulf Grenander) is available as a mathematical generalization of chemistry applicable for Everything, from molecules to thoughts.

We can now glue generators together and the bonds will tell us what combinations will hold together. This is a bit like chemistry: atoms (generators) are connected together into molecules (configurations) and the nature of the chemical bonds, ionic, covalent, and so on, decides what combinations of atoms will be stable enough to form molecules. [5A, p.83]

This is why Pattern Theory gives to a renegade chemist like myself a podium for an oration, but words are often too heavy for a chemist to convey **understanding**. A chemist usually expresses his or her ideas in the graphic form—as ideograms—and this is what I am looking for as a medium for communication. Like music and visual arts, images appeal to universal human nature. This is why the advent of TV was a real revolution in propaganda: the visual perception outruns thinking. The velvet coercion of TV is more powerful than prisons and concentration camps.

My intent, driven by my belief in the unity of the world, is to contribute to the development of a distinct **language** to talk about X-systems in the most general, but informal way, equally accessible to physicists, poets, chemists, and historians, as long as they are interested in tall problems that cast no long monetary shadows. Another metaphor.

Concerning shadows, I believe that Ulf Grenander, as well as, on a smaller scale, René Thom, Stephen Wolfram, and Gregory Chaitin (himself brilliantly referring to Leibniz) cast the longest **intellectual** shadows onto the slowly developing understanding of X-systems as **open systems**.

I use the term *open* not in the classical physical sense of exchange of matter, energy, and information with the environment—they are open in that sense, too—but in the sense of inherent **incompleteness** due to the phenomenon of **novelty**. X-systems are open to all of the above but also to a **future** that cannot be derived from the present—as Stephen Wolfram’s deep conviction and models testify [8]. If so, can we speak about **theory**? Not in the **contemporary** sense (here comes **future**, which is always before the date) and this is why it is a different kind of science. But we can still **understand** such systems. I see the “theory” of organic chemistry as a typical **understanding** tool, as open to future as a Lego set.

Whatever the new understanding might be, the grandiloquence of some pioneers should be forgiven until the course of history vindicates them and the steamroller of habit levels the highway asphalt over the former trail.

I hope to expand elsewhere on how computers reminded the timeless mathematics about the ticking clocks. Until then, here is a quotation (secondhand) from René Thom [7B] :

We cannot consider catastrophe theory as a scientific theory in the usual sense of the term. . . . [W]e must consider it as a *language*, a method, which allows to classify, to systematize empirical data, and which provides these phenomena with the beginning of an explanation that makes them intelligible.

Earlier I suggested [1A] the terms Aristotelian (A) and Heraclitean (H) for the two kinds of systems and, perhaps, sciences. **A-systems** are the subject of science as we know it and **H-systems** are waiting if not for a new science then for some liberalization of the existing science.

To understand means to tell somebody who can tell it to somebody else. Obviously, what we must have for this is common language. An example of such common language in the larger world is the universal language of nucleotides by which the **future** generations of organisms **understand** their predecessors and send a message to the posterity.

The previous paragraph is itself an example of the language of metaphors, analogies, and similarities, shun by most so-called serious scientists as metaphysics but

legitimate in the pursuit of understanding. Hannah Arendt's *The Human Condition* was written in this language on the other side of the great divide between sciences and humanities, but the divide is also **open to the future**—a strangely sounding phrase meaning that it could be closed. How? By an earthquake? Hannah Arendt was listening to the voices across the divide, among which the voice of Werner Heisenberg [6] was the clearest, operatically schooled in the widest acoustic range of Goethean traditions.

The new ideas are not going to undermine “real” science in any way. But they are still met with mostly indifference and rarely hostility (as in case of Stephen Wolfram; but many negative reviews still sound more like praise) because they are different. René Thom acknowledged a formal failure of his work. He came to a conclusion that the theory, met initially with enormous enthusiasm, had failed because nothing could be **calculated** from it.

For as soon as it became clear that the theory did not permit quantitative prediction, all good minds ... decided it was of no value. [7C]

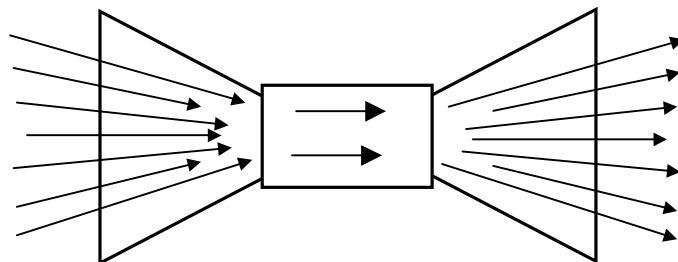
In other words, it did not pay in terms of grants and tenure. It turns out that Thom regarded his theory as a “new kind of science.”

This would not be the old science, but a new one, which would endeavor to provide explanations rather than mere description or predictions. [7D]

The problem of hostility toward “a new kind of science,” echoes, in a fascinating manner, another modern phenomenon: religious zeal against Darwinism. This is an example of a social pattern, which we should keep in mind. Whether this is an X-system pattern, is an intriguing question. Let us keep it in mind until we discuss the “rusty bolt” ideogram.

Speaking of money, there is another beautiful—and exact—analogy, promoted by biochemists, between **money** in society and **ATP** in living cells as universal currency of energy—the analogy (search the Web for “money ATP adenosine”). This is definitely an X-system ideogram.

Another example of what I call ideogram is the **bow-tie structure** [11]. It is not actually a structure in the common sense but a very abstract pattern of organization consisting of a large number of inputs being converted into a small number of intermediates further converted into a large number of outputs. In other words, “complexity $\rightarrow$ simplicity $\rightarrow$ complexity.” Two examples follow.



Nutrients

Metabolism

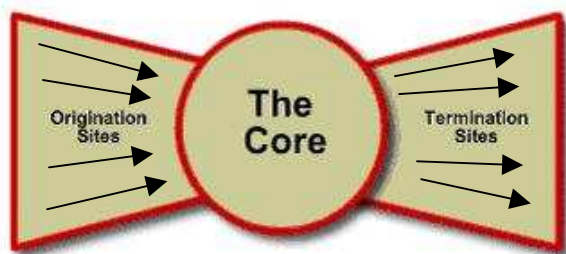
Biomolecules

Genes

Expression

Proteins

Sources [11A, B]



Organization of the Web.

The sites in the core are all interconnected with links. Sources [11C, D]

From the pattern and chemical viewpoint, the bow-tie ideogram means a decomposition of configurations into generators and a recoding and/or recombination of them into a new array of configurations. The combinatorial configuration space is always larger than the generator space. Further examples are, behavior, government and management, language and information processing, etc. There is something hidden in the bow tie ideogram, however: a complex system of rules or algorithms governing the processing. It is an open question, however, whether **the set of rules is also simple**. I

believe it is and [I tried to illustrate it](#) on the example of language. Genetic code is certainly simple. Another intriguing question is the **optimal complexity of government**. Excesses toward both simplicity and complexity of government can be dangerous, as American political history keeps illustrating with fresh examples.

ATP, rust, and even money are in the legitimate sphere of interest of chemists, who, however, are conspicuously absent from most discussions on X-systems beyond chemistry. There is very little on chemical complexity (for example: [9C]) and no consensus on measures of structural complexity, although algorithmic complexity seems to have passed the time test. The words **chemistry** and **catalyst**, however, belong to the common vocabulary from the street corner to political debate because they embody powerful analogies. On catalysis, see [1A-E, K, L].

Chemistry has a unique attitude toward **time**. It is concerned with the **intimate and delicate mechanism of change** and is not satisfied with the question: “what is going to happen?” because there are typically multiple outcomes. Anything we can imagine in the combinatorial chemical space can happen. The main question of chemistry is: “what is going to happen faster?”

Chemistry shares its approach to time with other sciences about X-systems, for example, with history (the French *Annales* School): it emphasizes the distinction between the long run (*long durée*) and the short run. There is an intriguing anti-symmetry relation between chemistry and history, however. Chemistry states that what we know about the long run—and we know a lot—does not tell us about what is going to happen in the short run, which is a matter of educated guess, best of all substituted by a simple experiment. History states that what we know about the short run—the period of the Clinton prosperity and the technology bubble, for example—could not tell us a bit about the next (current) radical turn in American history, which cannot be analyzed until long afterwards. The only safe prediction was that both would come to an end.

The next—third—turn could bring even more division, shame, and death, as well as profits, or it could heal some wounds and repair the battered roofing and flooded with

mud foundation of American system. Can we see it ahead of time? It may seem that the politics, unlike the vagaries of the market, is a game within a limited circle of players and statistics does not apply to it. But if the masses of voters are involved, shouldn't be there some thermodynamics in it? On the other hand, with the growing power of hedge funds and big mutual funds, the market might cease to be anything but a televised poker party. Since the masses follow the leaders, what politics can be the fastest? Such dilemmas constitute a typical problem of understanding history in the making. If we understand history, we probably will be able to look a little behind the time horizon. Note that this is a typical example of the need to express the new in terms of the old, as understanding should be.

Our views of society are highly diverging and polarized. Experiments with society are mostly unintended, sloppy, or rigged. While technology in experimental science brings us in a close contact with factual reality, technology in politics and business puts a TV screen between us and the factual truth. The modern presidential debate is a classical case of a rigged experiment. Can we have any degree of consensus in understanding "what we are doing," the central question of Hannah Arendt's *"The Human Condition?"*

If the primary question about an X-system is how stable it is, history is scientific enough to tell us that no X-system is stable forever. If the question is about the next stage, history is not scientific enough to tell us that, either. If the question is how soon the current state is going to become unstable and collapse we are able to evaluate that, but our evaluation immediately rises the next question: how soon the current state is going to become unstable and collapse after we have evaluated its stability and found it low.

Chemistry always asks: "how soon?" What happens faster is the most likely future. This is similar to the process of thinking, when out of a combinatorial immensity of all possible thoughts only one enters the consciousness, see [5C]. The abstractness of this similarity is exactly what makes it relevant for understanding X-systems. It illustrates the main problem with the rusty bolts (we will come to them later) of understanding "new kinds of science." In order to accept a new view of X-systems we have to abandon the old paradigm that provides us with daily sustenance.

At a closer look, the problem is imaginary. The ambiguity of the term “new” is responsible for some rusty resistance to a “new science.” A new refrigerator means that the old one is discarded. But it also could be a second refrigerator for food storage in the basement. I am inclined to leave only three necessary attributes to the notion of science: observation, understanding, and consensus. Thus, I do not expect the idea that the universe is a computer to come close neither to consensus nor to observation.

I believe that that the science of X-systems, when it takes its shape, will be not the new and only science but a second—**complementary**—science. It will be based not on closed axiomatic timeless mathematical or logical systems, but on open combinatorial systems of simple local interactions with laws and rules of limited rigor and validity and with yet unknown but definitely limited predictive power.

Not surprisingly, the enormous factual material about X-systems has been accumulated mostly in humanities. Science I (physics) and “Science” II (understanding) are the overlapping components of the human picture of the world, to which humanities contribute their intuition and flare.

Today complex systems are studied by Science I in terms of dynamical systems—an area as logically closed as any physical theory. The current interest in the less hermetic **data-driven dynamical systems** testifies to the drive toward realism, but such systems do not break out of the enclosure of formalism. Nevertheless, modern science of complexity is more conscious of the long and short run, as well as of the large and small cognitive grain size.

In the later three above-mentioned application fields [meteorology, chemistry, and physics] the data is typically sampled from a complex biological, chemical or physical *dynamical* system, in which there is an inherent notion of time. Many of these systems involve multiple time and length scales, and in many interesting cases, there is a separation of time scales, that is, there are only a few “slow” time scales at which the system performs conformational changes from one meta-stable state to another, with many additional fast time scales at which the system performs local fluctuations around these meta-stable states.

From: Boaz Nadler, Stephane Lafon, Ronald R. Coifman, Ioannis G. Kevrekidis, *Diffusion Maps, Spectral Clustering and the Reaction Coordinates of Dynamical Systems* (2004). [Meta-stable state needs a light push to descend to a stable state].
http://www.math.yale.edu/~sl349/publications/reaction_coordinate.pdf

It seems to me that Science I is moving toward **complex** theoretical solutions of **complex** problem (complexity square), instead of understanding “what we are doing” while creating the problems. Complex problems may have simple reasons, but not simple solutions. On simple reasons, see *Essay 28. Simple reasons* in [1M].

It is worth noticing that computation—the greatest most recent novelty of science—runs in intrinsic and measurable time and size (equivalent of space), unlike the classical mathematics, but very much like a chemical reaction. A unit of time is an elementary act of computation: a single beat of the processor clock.

Computer is a great embodiment of Leibniz’ idea that time is the sequence of events. When the computer is paused, its time stops dead. The unnatural property of computer is that it can be revived from its clinical death by the magic wand of a slight touch.

The passion of Gregory Chaitin for computation and the simple local rules of Stephen Wolfram, regardless of mathematics and philosophy, resonate sympathetically in my chemical heart. I was brought up in the openness of chemistry that weaves complexity out of 100 kinds of blocks of atomic Lego in the same manner art is weaving its complexity out of couple dozens of the letters of alphabet and maybe couple hundred color spots.

The recent *Meta Math!* by Gregory Chaitin [4A], in my chemical interpretation, carries a clear and universal message of mistrust in all closed logical systems, on which, as I see it, physics, but not chemistry, is grounded. As a chemist I see what looks to me as an underlying deep reason why perfection is imperfect: the world is in change, while abstract **Aristotelian reasoning**, like equilibrium thermodynamics, is heavenly beautiful

but never lasting. Physics keeps pace by breaking old paradigms—as a glass at a Jewish wedding—and espousing new ones. We all do that at new turns of history and personal experience. Regarding history, however, we do not even have a consensus-sanctified paradigm to smash.

Alas, what mathematics still lacks is the measure of energy (or stability, probably, related to mathematical elegance) of a mathematical expression, but human languages clearly rank by energy required to use them. English and spoken Chinese are easy to handle, German is heavier, Russian is very heavy, and Navajo is the hardest of all languages I am aware of.

In [1J] I casually suggested that Navajo verbs were in essence ideograms, like in Chinese writing, only not graphic, but acoustic ones. The acoustic analog of a pictogram would be a *sonogram* (not in the usual sense; *phonogram* is also taken): an imitation of a natural sound, which is regarded as a source for language origin, according to some hypotheses. I suggest a further (tentative) generalization of ideogram: **a symbol for representing an abstract idea as an entity of a very coarse grain, leading to simplicity.**

I have not escaped a metaphor in the previous sentence. Metaphor is the closest notion to ideogram. The difference is that metaphor names an object with a name of a different object, while ideogram names an abstract property of many objects with a single name and does it with a non-verbal symbol of its own. This, however, smells of a definition. I prefer to rely on demonstration, as, probably, Neanderthals did.

Concerning names, I see in Gregory Chaitin's description of understanding as compressing [4A] an echo of Henri Poincaré's casual remark that mathematics calls many things with one name. Ideogram is, therefore, akin to a mathematical symbol.

Complexity is a very tricky subject. The problem I have with complexity of finite sequences of zeros and ones, as well as with the finite output of a cellular automaton is that each of them is a closed object—if we leave infinity to mathematicians and theologians to wrestle with. I am uncomfortable with ascribing randomness (and even **regularity**, which is a much better term) to single objects and using it for a complexity

measure. My discomfort only deepens when I read in Chaitin's lecture [AIT = Algorithmic Information Theory]:

In these lectures I discuss philosophical applications of AIT, not practical applications.

Indeed, I believe AIT has no practical applications.

The most interesting thing about AIT is that you can almost never determine the complexity of anything. This makes the theory useless for practical applications, but fascinating from a philosophical point of view, because it shows that there are limits to knowledge. [4B]

This is as much overboard as anybody can go.

An alternative approach to complexity is possible. I believe that the property of complexity applies to open combinatorial **spaces**, such as configuration space of Pattern Theory, or molecular structures in general, or an individual language as a whole, and not to individual configurations in those spaces. My thesis, in terms of Pattern Theory, is that all individual configurations (structures) are equally simple or complex within the same configuration space defined by the generator space and regularity. To be concrete, all chemical structures, from water to DNA and proteins, have equal pattern complexity defined by the size of the Periodic Table and properties of atoms.

For the first awkward take on this difficult to accept—and formulate—issue, see *The New and the Different* [1K]. From this standpoint, all sequences of 1 and 0 have equal pattern complexity, I would say, about 2. It jumps to ~3, however, if we add number 2. As a consequence, while all chemical structures are equally complex (or simple), the history of chemistry is a record of growing pattern complexity, from the four elements of ancient Greeks to the first periodic systems and to its subsequent expansion. This applies also to larger structural blocks, such as carbohydrates, proteins, steroids, and aromatic cycles.

In addition to the above idea, I suggest setting aside any absolute measure of complexity. What we can evaluate is a **difference** of complexities within a larger space. Moreover, the difference matters mostly in terms of **more** or **less**. More exactly, I am talking about a partially ordered set (scale) of complexity values. (See *Essay 13, On*

Numbers, [1M] for more about partially ordered scales, for example, in Confucian ethics; in short, we cannot measure somebody's virtue, but can compare two virtuous persons).

The wide use of differences instead of absolute values is typical for traditional pre-computer chemistry. Differences, unlike absolute values, are always accessible and practical. Will you be **more** or **less** happy if you divorce XYZ and marry ZYX or buy UVW shoes?

To prefer relative values to absolute ones means admitting that algorithmic complexity must somehow include the knowledge about how the author of the algorithm understands the system and what is the size of the grain in that understanding. Thus, we can compare various computer outputs, but we cannot compare a computer output and a protein unless in a larger abstract system which would somehow include some knowledge of computers, as well as of chemistry, and, more dramatically, the knowledge of human nature. Nevertheless, this is exactly what I advocate in this essay: we need not the largest, but just a larger system.

I understand incompleteness as the inherent lack of a larger—in time, as well as in space—system to describe the system under consideration. To put it simply, in order to create a scientific model of eight years of American history (2000-2008), we need to collect the historical record for at least a century (1950-2050; we never know in advance for how long). We can monitor the expansion of the conceptual space by comparing the expansion of the vocabulary in use. This is why I am pessimistic about any “dynamical model” theory regarding X-systems. There is an additional reason for that: “dynamical model” requires (if I am not mistaken) a large enough statistical ensemble. Individual human mind, however, is incapable of operating with large number of cognitive entities. Nor, for that matter, are we capable of directly handling a large number of things and people.

We always maintain a certain density of information by well known hierarchical aggregation. Thus, contrary to popular opinion, the **chemists** who deal with **really complex** molecular structures **do not necessarily think always in terms of atoms**—they do not even write all of them in their ideographic formulas—but operate with larger blocks of stable fragments of structure. As everybody, they decrease the complexity of configuration space until it is manageable by human mind. The politicians, spitting out frozen clichés, slogans, and sound bites, use the same trick for managing the minds of the

public who has enough complexity to deal with in private business and family life. Not that there is anything wrong with that, except that the democratic elections become irrational. Love can be irrational, but an irrational vote could be literally suicidal or even murderous, if it is the vote of a court jury.

There is a curious document, *The Use of Complexity Science. A Survey of Federal Departments and Agencies, Private Foundations, Universities, and Independent Education and Research Centers*. October 2003. A Report to the U.S. Department of Education (<http://www.complexsys.org/pdf/ComplexityScienceSurvey.pdf>). The title speaks for itself. I see it as money well earned by riding a wave. Complexity must be practical.

Complexity is practical. As an example of the **kinetic consequences of complexity**, I regard evolution of language as simplification of grammar in order to increase the speed of communication and keep it up with the speed of events [1C], as well as with their complexity. By the same token, I anticipate the political leadership of the USA to be more and more superficial in the future, religion and obscurantism more and more attractive as a refuge from complexity, and the voter's behavior more and more capricious and self-damaging—until a new phase transition in the mechanisms of civilization.

I conclude **PART ONE** with another personal note. While reading Chaitin's exuberant book, I recalled my own excitement when discovering—long ago—Leibniz' ideas about time and space, the concept of meta-mathematics, the first publications of Stephen Wolfram on cellular automata, the idea of algorithmic complexity ("Kolmogorov-Chaitin" complexity, although Kolmogorov's contribution seems only casual), Ulf Grenander's books, and having recently discovered Hannah Arendt. Witnessing the birth of the modern chemical paradigm of transition state was also an unforgettable experience.

Blessed be ignorance that gives us the sharp joys of discovery.

I count on some tolerance of my going overboard with Chemistry of Everything. Well, this is just "Words, words, mere words..."

We are moving from chatting to making: cooking pasta, which is a real thing, and assembling a brushmobile, which is even more real than one would think.

PART TWO: MAKING

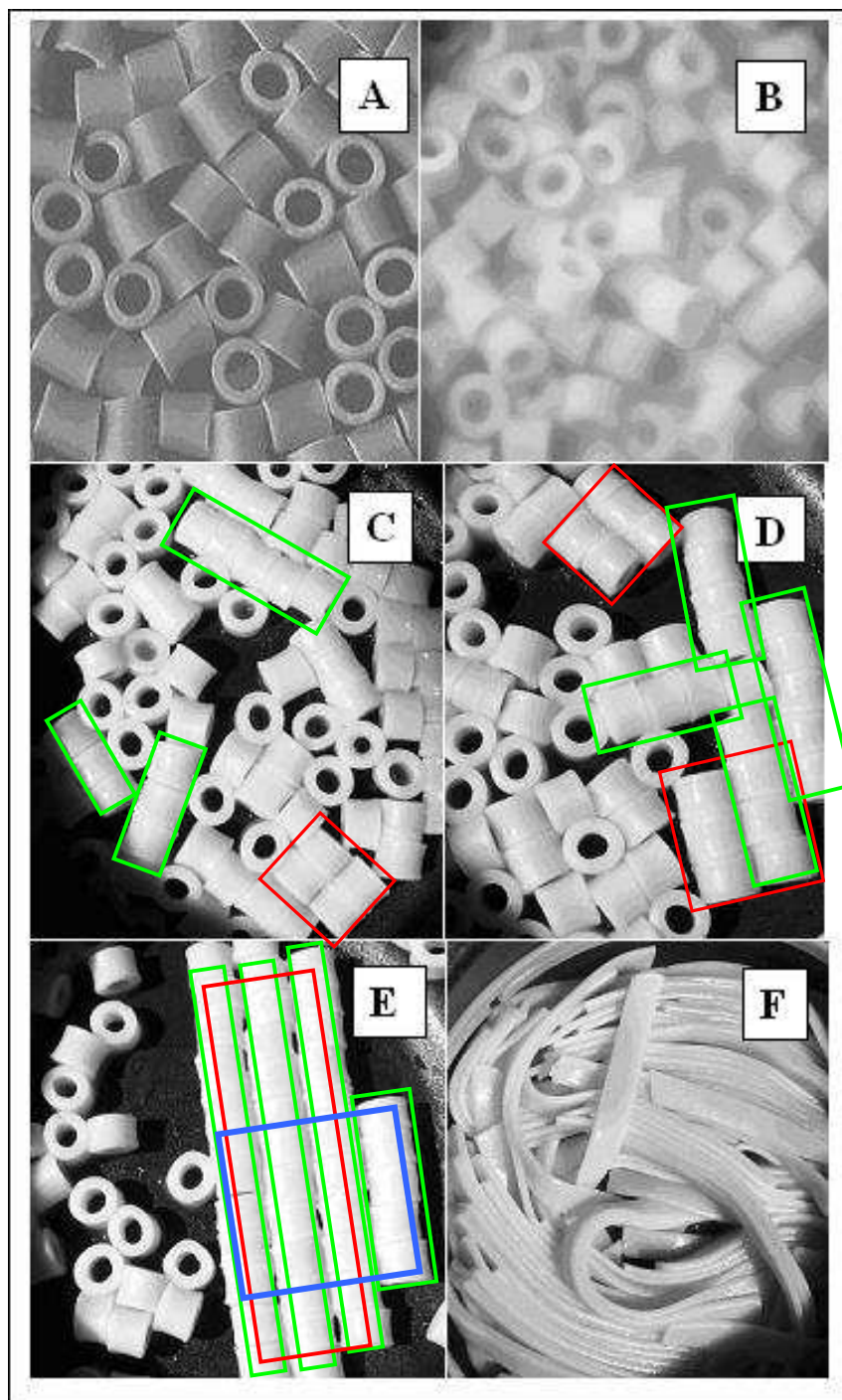


Figure 1. Pasta: **A**, Dry ditalini; **B**, Cooked ditalini in water; **C** and **D**, Drained and slightly shaken pasta; **E**, *Homo Faber* was here; **F**, Cooked linguini.

To take photos for **Figures 1A to E** and **2A**, I cooked some ditalini pasta. The diameter of ditalini is approximately equal to the length, which makes the circumference more than three times longer than the length. The cylinders have substantial flat ring areas at the ends.

The dry cylinders have only two axial orientations on a firm flat surface: vertical and horizontal. The cooked pasta, still in the water(**Figure 1B**), has more **degrees of freedom** at low effective weight than on a hard surface. But how many? To answer this question, we should collect statistics of the orientation and plot the distribution. Intuitively, I do not expect it to be random, unless in zero gravity, but I am not going to check it. The data will be true for as long as ditalini is on sale, cooking is done in the present manner and utensils, and the cooks still exist. I am interested not in what the cooked pasta tells me about cooking pasta, but about the world outside: the X-system in which pasta emerged, ditalini was invented, and which will probably exist after ditalini is extinct. I am interested in what the short run tells me about the long run, because all I can see is all of the short run and the past part of the long run, sometimes fragmentary.

The still photos do not convey any idea of time. Nevertheless, I am going to interpret the difference between the photos in **Figure 1** in terms of **stability** and **lability** which imply the notion of time.

Stability, points to the preferred direction of events in the long run: toward higher stability. Like energy (which it essentially is), it depends on the intensity of chaos, i.e., abstract temperature, in the system. A frozen abstract system at zero chaos does not change. I should be more precise: an abstractly frozen abstract system at abstract zero of abstract chaos does not change, which means that the Leibniz' abstract time stops. Nothing is stable in a very hot system even in the short run. Of course, long and short time are also relative notions, but all we need is some distinction between them. For example, an average human lifespan is long as compared with an hour, although both are short on a cosmic scale.

Physics abstracts from human presence and ignores the chance that a human hand will catch the falling Newtonian apple in mid-flight. History does not argue with physics but stretches human presence over particles and waves. Chemistry and biology take intermediate positions.

With my aversion to definitions and absolute values, all I can do is to distinguish between **more stable** and **less stable** configurations or states. While **configurations** are abstractions, **states** relate to a particular system in which not all configurations and their sequences in time are possible. Ulf Grenander reflects this subtle distinction by using the term **image** for an actually observed “realistic configuration,” not yet processed into the more idealized **configuration**.

In other words, a configuration is a mathematical abstraction, which typically cannot be observed directly, but the image can. [5A, p.91]

Photos in **Figure 1** are exemplary images in this sense. Images cannot be interpreted as configurations without some arbitrary participation of the mind or a man-made program. It is needed for choosing generators and rules of identification. Pattern Theory acknowledges the human presence in mathematics: “we introduce the equivalence relation,”[5A, p.91] we have to decide whether two images are **similar**.

A third principle deals with observability: given two combinations, when do they appear identical to an ideal observer (with perfect instrumentation)? [5B, p.3].

With some relative measure of time we can detect the differences in stability between two systems and the difference in the temperature for the same system. We do not need any absolute numbers for that, but we need a **human observer of the images**. Recalling Heisenberg’s prophecy [6],

When we speak of the picture of nature in the exact science of our age, we do not mean a picture of nature so much as a *picture of our relationships with nature*. [6, p. 29].

We can see the inherent difficulty with all formal systems as soon as we ask the question “Are we, humans, nature?” Or: “Are we the undercounted part of algorithmic complexity?” **We are present in any description of nature because we choose the size of the grain in the hierarchical generator space.** We have little choice only in the case of computation, where the universal grain is 0 and 1. I am not sure this is so, however,

because we have to code the non-numerical notions, like symbols $+$, $=$, and f (function), but my expertise in mathematics is closer to 0 than to 1. Besides, infinity—incompatible with anything human—creeps in, if not in computation, than in our chatting about it.

The difference between configurations and **images** comes to the foreground when we deal with human fantasy, creativity, invention, and planning, i.e. **imagination**, of course. I wish to draw attention to the ability of Pattern Theory to speak about both nature and mind in a unified language, or, in Heisenberg's words, about **our relationship with nature**.

When by nature we mean X-systems, we should get used to do without anything perfect, exact, definite, and precise, as we already do in calculating the behavior of complex inanimate systems like bridges, airplanes, and weather. They all can let us down.

Back to pasta. The cooked cylinders form relatively stable coaxial assemblies several pieces long (oligomers, as a chemist would say) because their bases can stick together along their flat cross-cut rings. (**Figure 2B**). The significant, almost biological regularity comes as no surprise because pasta is man-made. Similar tendency to form organized structures is seen in linguini forming strands of parallel filaments, **Figure 1F**. It is also used in liquid crystal electronic displays.

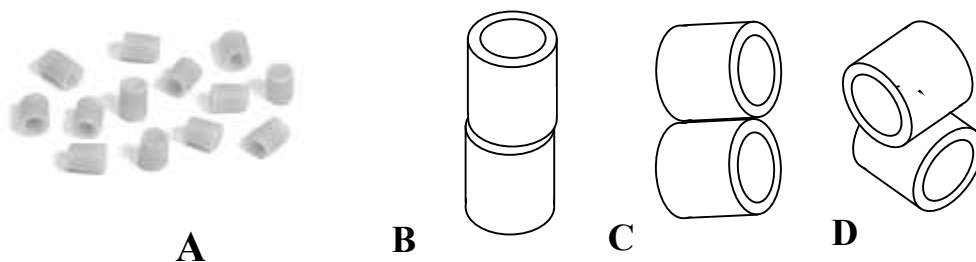


Figure 2. Pasta bonding: A, no bonding; B, at the base surface; C, along the generatrix line; D, at a point.

Other types of connection, such as **Figure 2C** and **2D**, may occur as dimers but hardly as polymers. The area of contact along the generatrix of the cylinder is much smaller than that of the basal ring and, therefore, the bond of **2C** type is weaker than that of **2B**. The **2D** type connection is even weaker.

For elongated particles the parallel bonding is more stable than the consecutive one, compare with **Figure 1F**.

The green rectangles encase single linear strings and the red ones emphasize a weaker parallel bonding. The blue frame in **Figure 2E** displays an **unusually high degree of regularity** in two dimensions, which reminds a raft structure. This image, depending on the angle of view, looks either **artificial** or, just the opposite, as **natural** as a biological formation. No wonder, because, philosophically speaking, it is both: it is artificial because here I became *homo faber* and arranged pasta bit by bit by hand and not by shaking; it is naturally biological because I am alive and I have a mind of my own. This painful relativity of life and mind has been causing endless discussions about both, but on the platform of Pattern Theory I have as little problem with mind as chemists have with life. Which means: little but not nil, maybe even a lot.

An interesting side dish of a problem comes here into view. How can we detect an artifice, for example, on another planet? The evidence of artificiality of **2E** can be seen in the **absence of the intermediate** forms between chaos and extreme order. Artificiality, so to speak, is anti-Gaussian and in this sense abnormal. The absence of intermediate forms in paleontology comes to mind as a sign of both natural and artificial origin of species. Artificiality here means that the species, probably, develop not (or not only) by a random genomic walk but in response to a new source of non-equilibrium order.

The problem of elephant's trunk—antagonizing biologists over Darwin and even Lamarck and Cuvier—remains a mystery. In biology it has the status of Fermat's Last Theorem with a big difference: it is a problem about possibility and not about impossibility, as in mathematics.

Now we are coming to the main treat. Once arranged, the regularity of **2E** type has a significant stability because the **multiple weak bonds** along the generatrix keep the entire pasta “raft” together **as if they were one strong bond**. Only **as if**, because there is no such single bond and the aggregation can be explained in terms of overall stability. In other words, stability is additive: it is a sum (approximate) of increments.

This is the heart of chemistry: the global property of a structure can be derived from local components. It seems that in social chemistry the global property can be imposed from a local point (King Hammurabi or Joseph Stalin), but the star topology is reducible to individual bonds. To follow the law or not is our personal decision. We obey because otherwise our stability will be decreased. I believe there are physical theories based on strictly local interactions, but I am not an expert. Look for works of physicist Gerhard Mack on universal dynamics.

Once formed, the raft disintegrates only at a higher chaos than that of its creation. In order to bring the raft to existence and make it stable, I had to perform work, i.e., a series of gentle movements against some weak forces in a particular order. Moreover, an **idea** of the final configuration in my mind preceded the actual work. The idea was neither an image in PT sense, nor a single configuration, but rather a pattern of a 2D arrangement similar to 2D natural images. The idea itself had developed in two stages. Initially I only wanted to make long strands of cylinders, but having made a couple of them I decided that to put them side by side would make more effect. The artificial raft is an **ideogram** of my idea of artificiality (imposed regularity). There could be a variety of graphic symbols for this idea and even a superficial browsing through literature on semantics and semiotics (see some examples at [10]) shows that everybody can invent his or her own symbols. Nevertheless, the symbolic systems could be arranged in order of their complexity. There are some standard Platonic components in them, like point, line, arrow, and circle.

The bits of pasta are held together only at low generalized temperature. If shaken above a certain level, they can separate and reassemble. The intensity of shaking or stirring, therefore, is a **metaphoric image** of the temperature, which illustrates the **idea** of what chaos, temperature, and bond means in physics, chemistry, and beyond, including history. This image is generated by my mind—reverse-engineered—from a configuration of an idea and presented to the reader as a language construct.

Temperature is an ideogram, but I cannot imagine a static visual symbol for it. It can be well rendered in dance, however.

Thus, high social temperature, often called “political pressure,” (indeed, high temperature increases the pressure of the gas in closed vessel), or “turmoil” can split a coalition or weaken the bond between the leader and his party.

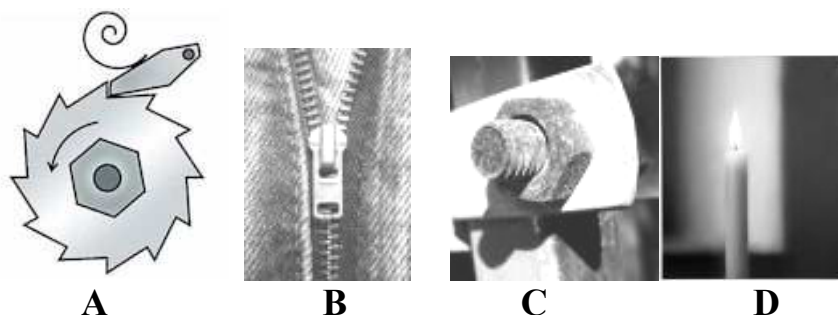
Note that I know nothing about the actual physical mechanism of interaction between the pasta cylinders. Nevertheless, I venture to propose a kind of understanding by choosing the **language** of stability: the bits of ditalini stay together because it is more stable than to stay apart.

IMPORTANT: bonds can be **positive**, so that the bonded state is more stable than unbonded, and **negative**, when unbonded state is more stable than divided. In the second case, a force or work is needed to keep atomic units together, as it commonly happens in modern societies, especially, created, like Iraq, by external initiative or, like Communist China, by a revolution. In such cases the internal binding force can be quite brutal.

Figure 1 leaves us in the dark about the origin of life, but it tells us something about the origin of complexity. First, it can grow gradually and irreversibly because of a variety of bonds that generators can form; second, the concepts of life and mind do not have sharp borders in the language of generalized chemistry, i.e., Pattern Theory. It might be possible to erase borders completely in a language of Pattern Theory enriched by adding the **kinetic** concepts to the **thermodynamic** ones.

On the above foundation of pastology one can devote his entire life to elaborate study of the world of pasta. Far from that, I further intend to build just a little more on that foundation by emphasizing the kinetic aspect of generalized chemistry, although in vague, tongue-tied, non-mathematical terms, which, as I heretically believe, are most appropriate for X-systems. In chemistry, business, and politics, as in cowboy movies, the quickest shooter wins ... in the short run.

Lability and stability are two characteristics of molecules regarding their propensity for change.



**Figure 3. Lability (A, B) and inertness (C, D):
A, Ratchet and pawl; B, Zipper; C, Rusty bolt; D, Candle.**

Lability or **reactivity** (in chemistry), unlike stability, means that the change from one stable configuration to another, even less stable one, occurs pretty easily. The word comes from the Latin *labilis*, tending to slip. The politician that easily changes positions can be called labile. Bureaucracy is **inert**, difficult to move, which is the opposite of labile. When the resistance of bureaucracy is overcome in one particular case, the next will be as tough. The furniture is hard to slide on a carpet, much easier on wooden floor, and even more labile if low-friction pads are under the legs.

The concepts of stability/instability and inertness/lability are confusing because they overlap in common use and even students of chemistry often make mistakes.

Intuitively, both instability and inertness should have stability as the opposite, and they indeed have. Stability, however, as many widely used terms, has at least two meanings: immediate (short run, in a particular act) and a prolonged (long run, at unspecified circumstances).

Their distinction can be clarified with pictures in **Figure 4**.

1. Ratchet and pawl. The ratchet wheel, **Figure 3A**, easily turns only in one direction because the transition from one position to the next runs into obstacles of different strength, depending on the direction. This **asymmetric** system is labile counterclockwise and inert in the opposite direction. It is **labile**, however, because it takes only a little work to change its state. Otherwise it is sturdy enough and if not exactly reversible, then movable into any initial position.

The ratchet is, in my eyes, an ideogram for irreversibility by design, not by thermodynamics—a very important distinction. This kind of irreversibility has human or biological origin. It is life-made, if not man-made.

There is significant recent literature on ratchet as a general principle [11], or **ideogram**, as I would say.

2. Zipper, Figure 3B. Multiple weak bonds formed by the teeth of the zipper form a strong bond between the two connected pieces of fabric. The connection is labile and symmetrical (reversible) because the bonds can be locked and broken one by one. This type of connection is typical for the biochemical structures of life: the coiled enzymes, structural proteins, and nucleic acids can be unfolded relatively easily by an excess of small molecules capable of forming labile bonds with them.

The typical chemical bonds that form the skeleton of a molecule are strong (covalent) bonds, difficult to break up. They are inert, but not necessarily stable.

Now we can step aside and watch the zipper from the Archimedean point. We immediately note the master of the zipper, whoever he or she is.

Why does the zipper open? Because the final state in the largest possible system, including a human, with bonds to and from the zipper is more stable than the initial state. The human master of the zipper feels relief or satisfaction after having opened it. The tension drops, but it might jump up next moments, if two humans are involved. **The zipper stands as an ideogram** for much larger and more complex X-systems, such as a conflict between two powers over a border incident (easily reversible in principle).

3. Rusty bolt, Figure 3C is trickier than it seems. It is **inert** the first time you try to unscrew it, but right after that it can behave like the zipper, unless again abandoned to the elements. I choose it as ideogram for a rejection of new ideas by a majority. Note that the rusty bolt sits tight because of multiple weak (non-covalent) bonds.

Some people display the rusty bolt pattern of behavior: reserved and cautious the first time but friendly and warm afterward. The same pattern can be seen in resistance to new ideas. “Screwed up” is another ideogram, effective in politics and business.

4. **Candle, Figure 3D**, is my favorite example. It is made of paraffin, a mixture of hydrocarbons capable of burning in contact with the oxygen in the air, which means that the **stability** of the candle-air system is low. Its **lability**, however, is also low, so that it can be stored indefinitely, unless ignited, while an iron nail reacts with the same oxygen and turns into rust in a moist atmosphere.

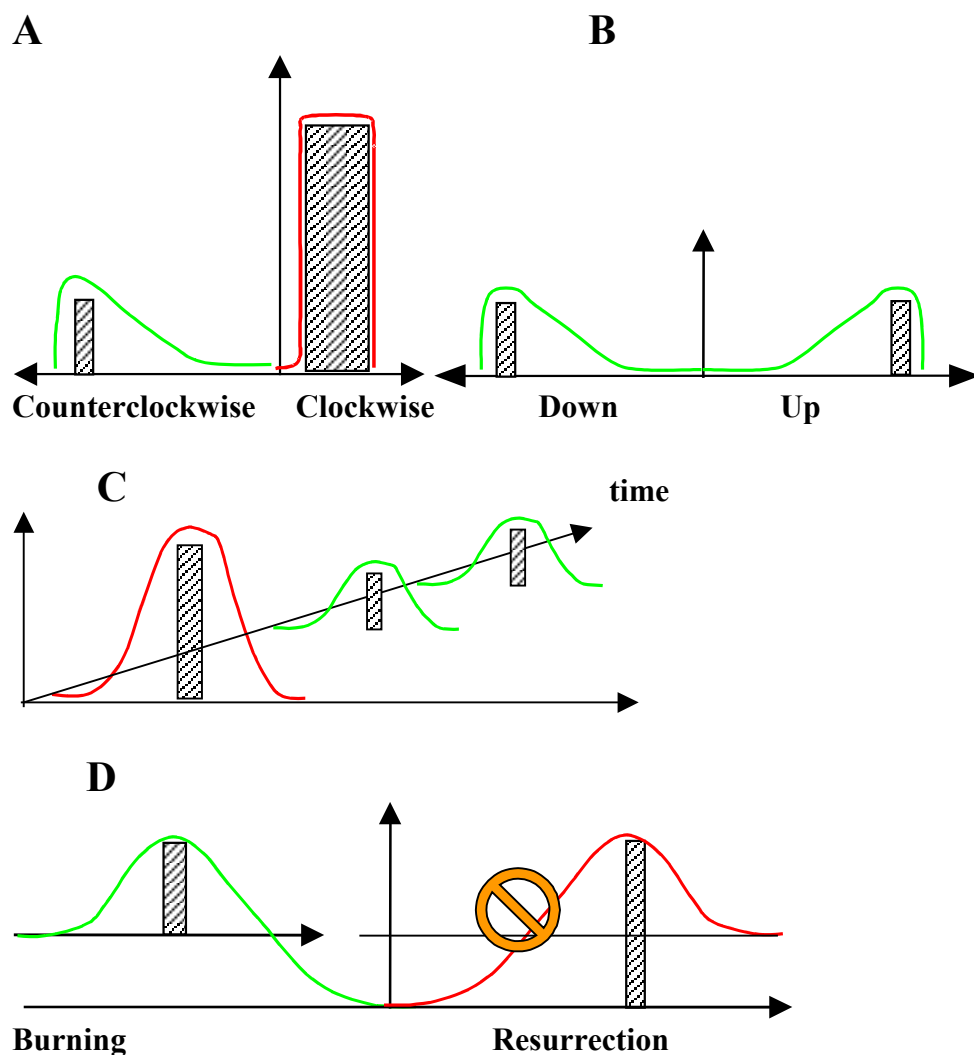


Figure 4. Transition barriers of: A, ratchet and pawl; B, zipper ; C, rusty bolt; D, burning candle (vulgarized!).

White phosphorus, as an extreme example, spontaneously ignites in the air and burns brighter than the candle. The red phosphorus is **inert** and does not change if

exposed to air. Both consist of exactly the same atoms, like Dr. Jekyll and Mr. Hyde, only arranged differently.

High stability, therefore, means that the system is inclined to remain in this state no matter what and not to move to less stable states. High lability means that “no matter what” does not matter and the system will move if slightly prodded.

The reason why, unlike the Phoenix bird, the candle cannot be resurrected is that the products of the burning are much more **stable** than the starting candle and oxygen.

The physical-chemical picture behind **stability** and **lability** is rather complex and technical. As far as **lability** is concerned, most chemical transformations are reversible and a dynamic equilibrium establishes between all participants and products of transformation. Natural lability has no ratchet properties. The position of the equilibrium depends on the temperature.

The principal reason for the irreversibility of burning is that the heat of the burning, as well as the gases, are dissipated and dispersed over a large volume. I don't know about the Phoenix birds, but if a hundred sparrows are released from the cage, there is no chance they will come back without a team of skillful catchers.

The candle as ideogram stands for an **unstable inert system in a precarious environment**. It is just a little bit stable that a gasoline can with a matchbox nearby. Today I would associate the intact candle with all nuclear weapons on earth and the burning candle with the process of burning mineral fuel, ignited by the Industrial Revolution. The intact candle is in the initial state of the process and the burning candle is in a long transformation that we can observe in all detail. In the short run, the mineral fuel will be exhausted, but in the long run—we do not know how long—there is a chance that plants and algae will do the job of catching the carbon sparrows, using the sunlight as the source of energy. This is exactly what they have been doing since life emerged on earth. The problem is that the long run of Industrial Revolution is a very short run in the history of biosphere.

The fact of crucial importance is that we are unable of predicting what will happen next. What we call a true historical prediction is a winner in a race between many runners. Of course, somebody with a good record has decent chances. From the human standpoint, pessimism is as justified as optimism. This is a typical example of the openness of X-system. The largest X-system on earth is always pregnant with novelty. All we can say is that some human societies will adapt better to the burning process than others. *Collapse* by Jared Diamond [3C] is, by the way, another example of the Archimedean point taken by an author in a non-technical language.

Answering the call of Hannah Arendt to think about what we are doing, what comes to my mind first is burning the candle at both ends.

I believe that with the above examples of some very general patterns of systems behavior I follow in the steps of René Thom's, *Structural Stability and Morphogenesis*, [7A] see **Figure 5**. What he called archetypal morphologies, I would call ideograms in the sense some Chinese and Egyptian characters are. See [1J]. I regard ideograms as highly compressed, large-grain alternatives to dynamical systems.

I have already used the term **ideogram** several times, but my description (no definitions!) “any symbol for representing abstract ideas” needs some illustrations for symbols other than acoustic, pictorial, or gestural, i.e. verbal. There is a problem, however.

If you decide to venture into the jungles of X-systems, you must be prepared to get immediately lost in the thicket of literature that grows right before your eyes. As soon as you cut through a couple of publications, twenty new ones spring right from the ground or dangle from the branches. Moreover, you have to be prepared to venture into quite disconnected and distant areas of knowledge—as if you were required to speak all languages of the globe and have degrees in all sciences. One cannot do all that without a good deal of ignorance, hubris, and naiveté. Even some respected authors, who use similar terminology and ideas and live in the same period, seem not to notice each other's presence. As a striking example, semantic topologist Leonard Talmy in his vast bibliography misses semantic topologist René Thom and scores of authors writing about

patterns do not even mention Pattern Theory. The excitement, however, is exactly in mapping them all in a compact single image. What helps is gradual triangulation: somebody can see two distant mountain peaks and put them side by side in a single frame. This is how the science of Everything is being built. Formal systems are picket fences around private lots.

The literature on graphic representation (topology, more accurately) of meaning is large, growing, and with little consensus in sight. I include select references at [10]. I am planning to return to this subject and compare the ideas of cognitive semantics (Leonard Talmy) with Pattern Theory (Project **Golem** of Ulf Grenander [5C]).

Ulf Grenander designates **content** and **connector** (i.e., structure) as the two aspects of a **thought configuration**; Leonard Talmy calls **content** and **structure** (i.e., connector) the components of cognitive representation.

Here I limit myself to René Thom as one of the founding fathers—and a martyr—of the subject.

Thom's idea, as I interpret it, was that a graph could represent an essential type of change in the state of a system, which he called a catastrophe. His graphs, however, are pictures and not graphs in mathematical sense. It comes as no surprise because a graph, i.e., simply speaking, a combination of points and connecting lines, is static by its very nature.

Thom's ideas and illustrations are often vague and his text is sometimes a banal chat. I think it is unfortunate that his work of cardinal importance remains unsettled and unfinished, although his ideas were used or emerged independently in linguistics. For more about ideograms and metaphors, see [1C, Chapter 6].

My primary exasperation with Thom is that I see nothing that a chemist would qualify as structure. Ironically, while writing about structural stability and morphogenesis, Thom never actually cared about structure and was indifferent to “material evidence” of making.

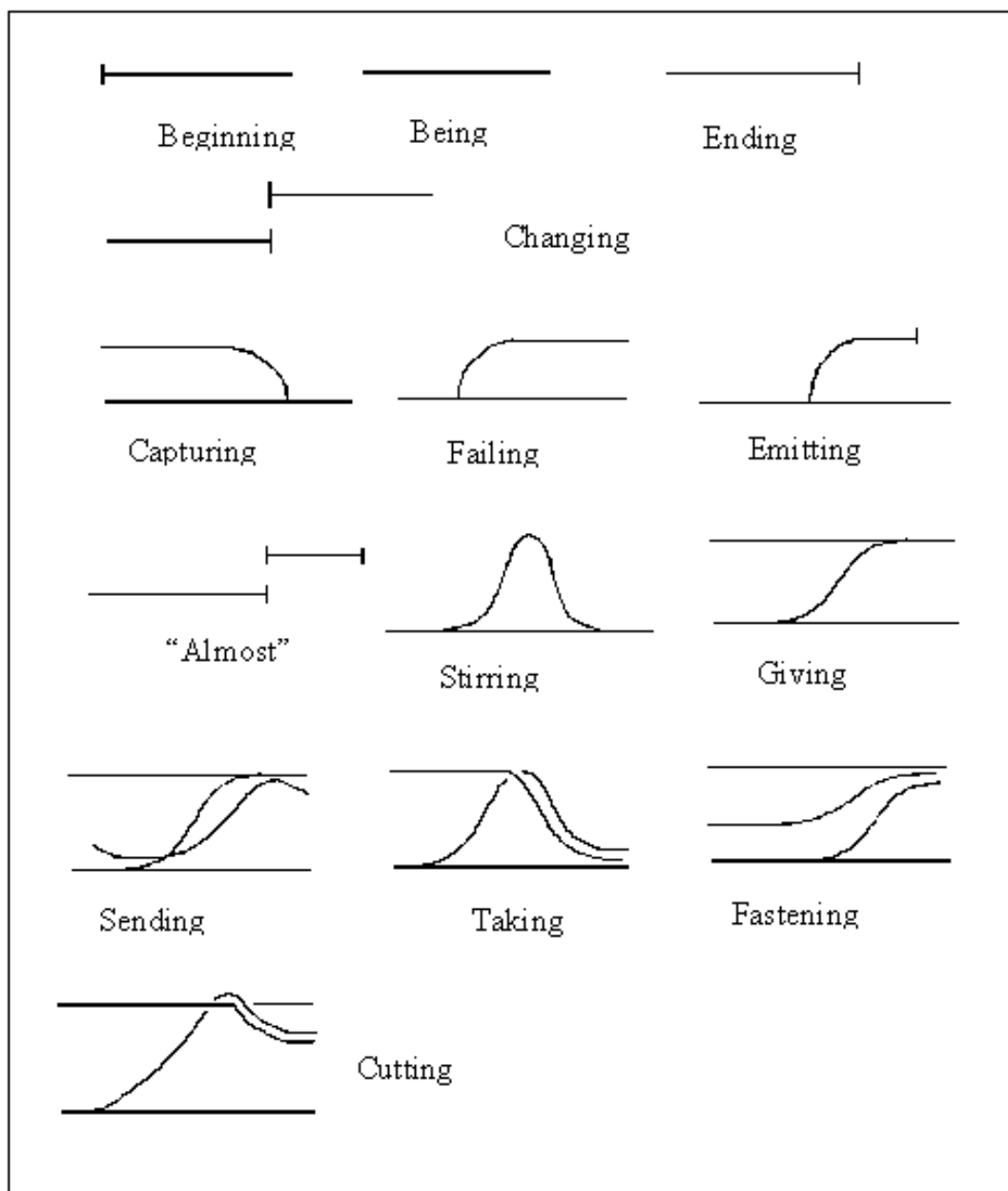


Figure 5. Abstract patterns of change (archetypal morphologies), along René Thom.

For real structure as the chemist understands it one should turn to Ulf Grenander.

Notably, only Thom's *fastening* includes three parallel timelines. It would be logical to assign three timelines to all cases with donor, acceptor, and the migrant: giving, taking, and sending.

Stirring is the only "one-line" pattern in his René Thom's classification. This is where the closed system fails to open to the novelty of X-systems which never come to the same state. As a chemist, I would interpret Thom's *fastening* as bonding, for example,

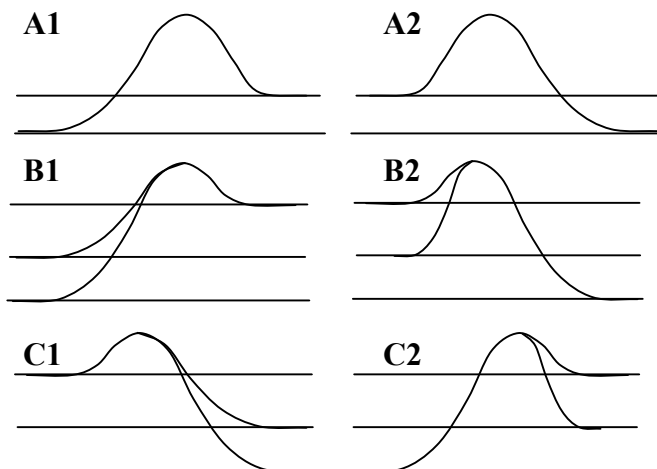


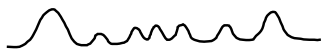
Figure 6. "Thomist" patterns of abstract change (A), binding (B) and splitting (C).

which would require a reverse *breakup*. Adding the stability dimension, I would use a *stirring* transition hump in "Thomist" ideograms, see **Figure 6**, for destabilization **A1**, stabilization **A2**, and their combinations in binding **B**, and splitting **C**.

Ulf Grenander's operations of pattern dynamics, ADD, REMOVE, MODIFY, etc., applied

to generators and bond couples, conform to those of chemistry. They include formation and breakup (more generally, modification) of the bond and removal, insertion, and substitution (more generally, modification) of a generator. They all amount to a breakup and formation of a bond, but, unlike anything I am aware of, they accommodate the property of **novelty** which distinguishes the X-systems from the traditional closed ones.

If Thom's patterns are reduced to horizontal timelines of stability alternating with ascending, descending, or hump-like transitions, they will conform to the familiar chemical minimalism. In [1L, Fig. 21.8, p. 284] an irregular stability graph



is used to portray the period of French history starting with the French Revolution, the latter itself looking like the back of a stegosaurus



[1L, Fig. 23.1, p. 323].

Coming back to pasta, its “chemical physics” is illustrated in **Figure 7** . The vertical axis corresponds to increasing generalized energy and decreasing stability.

Two pasta cylinders can be disconnected (**A**) and connected (**C**) and (**D**). If the system is “heated” by shaking, a certain equilibrium establishes between all possible mutually convertible more or less **stable** forms. This conversion occurs through a set of very unstable and ephemeral states of mutual reorientation and rearrangement, as, for example, A^* . The asterisk emphasizes its transient and both highly unstable and labile character. It can slip (remember? **labile** comes from the Latin for **slip**) toward **C** and **B** or dissociate into **A** .

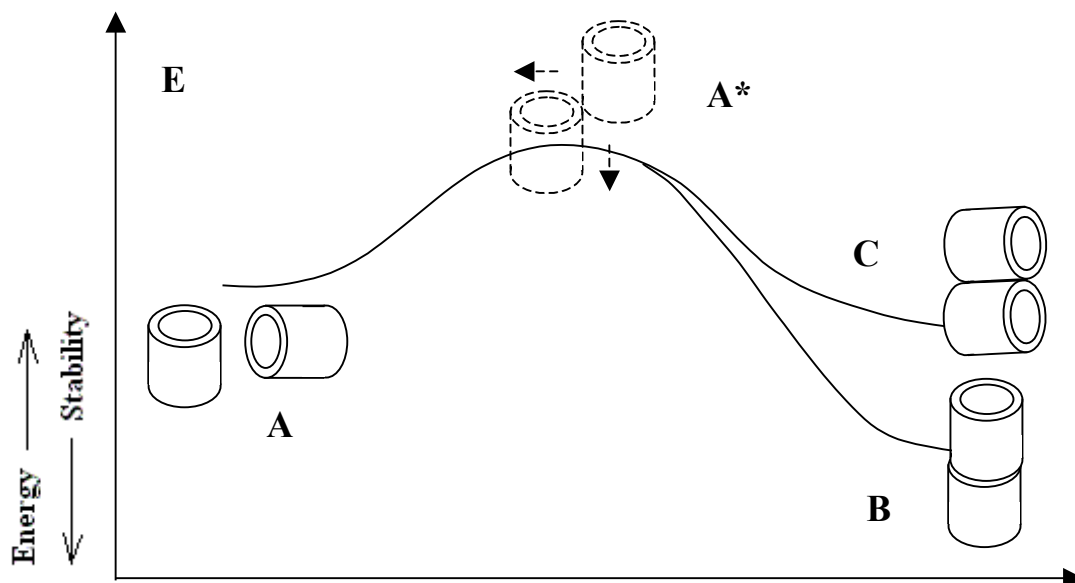


Figure 7. Interaction of pasta cylinders.

We can evaluate stability experimentally by observing the pasta behavior and comparing the average life time of the stable states, as well as of the transition state, depending on the degree of chaos. The transition states are very short living.

The main premise of the theory of transition state in chemistry is that the speed of the transformation from one stable state to another decreases with the height of the transition barrier. For example, the transition barrier from **A** to **C** is a function of the energy difference between **A** and A^* .

The exact numbers for X-systems can hardly be available and even if they were, they would be of no importance. What matters is the comparison of a few alternative pathways of transformation. Of course, as Michael Flynn noted in his book, the standardization of the society would drastically simplify predictions.

A uniform, docile society is more predictable, and Theirs [clyologists'] forecasts would be simpler and more precise" [3A, p. 108].

The problem with predicting the future is that you cannot ask whether an event X will happen unless it has already happened. Otherwise you do not have even a name for it. In your imagination you have to invent new chimeras and give them flashy names. This is still an open question whether there are patterns of historical events that cover all foreseeable and relevant future, and I believe that we should find the answer. Imagination, fantasy, and thought experiments are instruments in a laboratory for experimenting with the future. To think takes much less energy than to wage a war or build a sandcastle of a paradise on earth. Imagination is equally necessary for a chemist and for a detective. See [1A].

In order to compare a few scenarios (called mechanisms or pathways in chemistry) we need some criterion to distinguish between more probable and less probable ones. In other words, we need some knowledge about the **preferred direction of events**, and the first step toward this knowledge is the admission that the preference exists. Physics is the science of possible and impossible. The Newtonian apple can fall down but cannot jump up from the ground on its own. Within an X-system, however, it can move against gravity from the ground into the basket. The Newtonian horse can neither stop nor turn on its own. Chemistry is less radical: it is about predicting the outcome of the horse race. History is all about twists and turns.

The following example illustrates a special case of a preferable direction of events.

A property of an object is called isotropic if it is the same in any direction and anisotropic if it changes. Animal fur, for example, is smooth in one direction and rough

the wrong way. A wooden board surface is smooth along the grain and rough across. Corduroy fabric is another example of a highly anisotropic surface. If an anisotropic object is placed on a rough surface, chaotic disturbance moves it in the direction of the minimal friction. In **Figure 8**, a brush with orderly bent (anisotropic) bristles is placed on a rough isotropic surface. Chaotic disturbances, symbolized by $\leftrightarrow$, result in a sliding of the upper piece in the direction of the least friction.

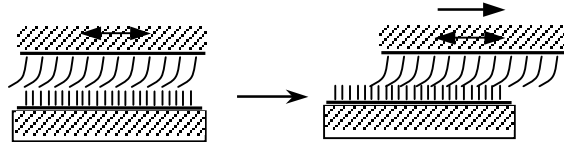


Figure 8 Irreversible lability in the case of anisotropic friction

Figure 9 presents a photo of a “brushmobile” (not related to Art Dog) capable of moving and even climbing up a slight slope. It has a couple of bent brass wire brushes fixed under a small vibrator.

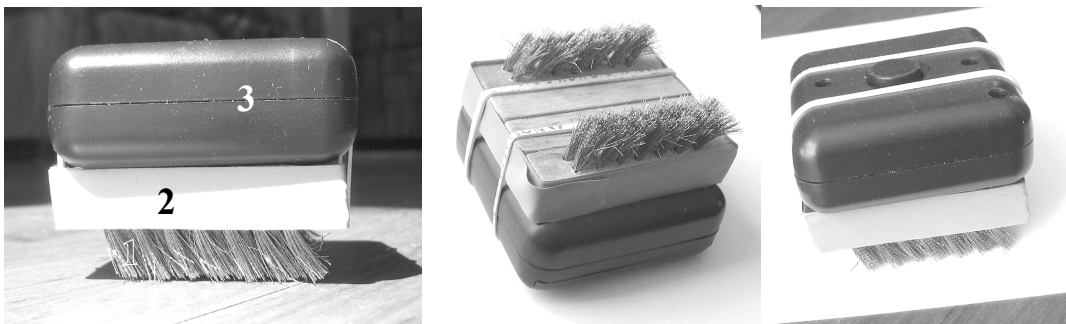


Figure 9 Brushmobile. 1, Brush; 2, Platform; 3, Vibrator with a battery inside.

The working toy model moves because it dissipates the electric energy from the battery, wasting most of it on friction. It also moves without a vibrator if placed on a vibrating surface. On a planet with chaotically vibrating surface the brushmobile could transportation loads against gravity. It embodies an abstract pattern that would be very difficult to symbolize graphically. A simple arrow $\rightarrow$ does not tell the whole story. This

emergence of regularity from chaos is the long known ratchet effect, widely used in technology, for example, in clockwork mechanism, as well as in cellular mechanics.

NOTE: Readers with background in engineering could compare the brushmobile with the clever **Ultrasonic Motor** (USM), in which the circular movement is generated by an ordered circular wave of mechanical deformation of a surface in contact with another high friction surface. The literature on USM with discussion of anisotropy has been growing and some is on the Web. An USM-like analog of brushmobile could probably work on purely chaotic deformations and jolts, using anisotropic friction.

As it was shown by Richard Feynman, no order can be produced from pure **thermal** chaos, unless the system is far enough from equilibrium. This may seem to contradict the history of technology with human mind as the source of order. We actually produce most of our mechanical work from thermal energy, but only until the system does not come to a halt. On a snapshot, our technology and the global civilization are in a steady state. Over a longer time segment, it is homeostasis, which is different from the steady state because of a series of distinctive transitions. The curves for the French Revolutios on page 34 correspond to homeostasis, not to a steady state. France has been inhaling and exhaling in a perturbed homeostasis ever since the Revolution. America, of course, is not exempt form riding a serpentine bumpy road and turning read, blue, and white in the face.

Life on Earth must have come from somewhere. The aggregation of multiple weak labile bonds into strong labile bonds, in my opinion, is the crucial source of order in the genesis of life. We can say the same about the mind, which is essentially a device for perceiving weak but repeating regularities as configurations bunched together into recognizable patterns. This is the same type of process that creates river beds—an analogy noticed by C. H. Waddington, whose term *chreod* was borrowed by Thom. The Grand Canyon, however, would never be possible without gravity which is responsible for the asymmetry of the system.

The precipice between river flow and social evolution seems as deep as the Grand Canyon itself. To bridge it is exactly the point. One of many possible definitions of X-

systems will be “ a system in which the Mississippi Delta (Grand Canyon is too phlegmatic) and social evolution are similar.”

Let us take economy as an example, in which I am an observer, but no expert, however. I privately believe that the machine of economy, starting from ancient times, works as a brushmobile, pumping the distribution of wealth against gravity (entropy) to high inequality in spite of the alleged chaos of individual actions. While the market is chaotic, rent, wages, and profits are as asymmetrical as gravity. The chaos of economy can be compared with a distribution of hail falling from the skies, while the fall is as predetermined as the rise of the kite jerking and wiggling in the wind.

The principle of the machine was described, on a different occasion, in the Bible as “For whosoever hath, to him shall be given, and he shall have more abundance: but whosoever hath not, from him shall be taken away even that he hath.” (Matthew, 13, 12). While the market is chaotic in the sense that deals are not globally coordinated, the sides

are driven by the interplay of the instinct of survival and the instincts of domination and enrichment, both creating **asymmetric friction** to other side's move. Our human nature is openly anisotropic: we **want** to slide in the preferred direction only: up. Even the suicide bomber hopes to ascend to heavens.

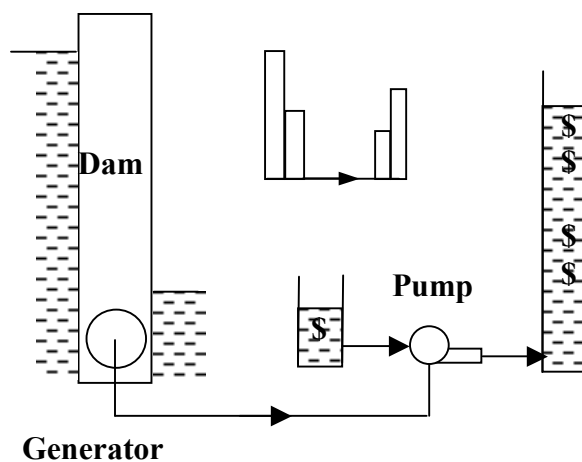


Figure 10. “Wealth pump”

Figure 10 (“wealth pump”) metaphorically illustrates the

asymmetry of X-systems from the energy standpoint. Hydroelectric generator is driven by the difference of the water pressure on both sides of the dam. The energy brings into motion the pump which works against the water pressure in two communicating vessels. The entire system consists of two subsystems: the left non-equilibrium subsystem maintains the right one far from equilibrium. If the whole system is insulated, sooner or

later the differences in the levels of liquids will disappear. A more compact symbol for the system is seen in the upper part of **Figure 10**.

To be more specific, the ideogram equally applies to:

1. Production of electric energy from the hydraulic energy of a river or from mineral fuel and its use for work,
2. Production of energy in living systems from sunlight or chemical compounds and using it for maintaining the integrity of the organism which is alive only while it is far from equilibrium.
3. Maintaining the unequal distribution of wealth which characterizes all organized societies, starting at least from the Sumerian civilization. Dollar signs in **Figure 10** symbolize that.
4. The concentration of wealth supports not only the complex system of economics, but also arts and humanities, as well as the form of government, and ideologies, sometimes, conflicting. That was, probably, the underlying idea of Marx.

Ironically, it applies also to moving ratchet devices. As newspapers have recently announced (2006), “the scientists made water flow uphill.” In fact, it was a case of a ratchet effect, [11C], which required a dissipation of heat, falling neatly under the ideogram in **Figure 10**, in the company of the brushmobile and all water pumps in the world.

The difference and interplay between strong (covalent) and weak bonds in chemistry is a separate and very specific subject. More can be found in [1] and, in chemical context, on the Web. It is very meaningful in social context. People in the West are sometimes surprised by the tolerance of the millions of Muslims to the terrorism of Muslims against other Muslims. They were also surprised by the patience of the Soviet people toward the Communist dictatorship. I believe it is a rewarding subject to investigate in terms of the strength and multiplicity of social bonds in different societies.

Freedom is a few (or even none) strong bonds in the sea of fleeting lability. Tribal and repressed societies, under the watchful eyes of rituals, have little lability and a lot of strong bonds.

According to Darwinism, the deep nature of evolution is chaotic. This may be true at a microscopic level, but there is a deep asymmetry on a higher level: the species adapt in order to go on with living, not to collapse. The movie *The March of the Penguins* is a heartbreaking illustration how far the adaptation can go. As the brushmobile moves only forward, the species move only toward procreation and normally not to self-destruction.

Along our contemporary views, which might be possibly disputed, plants do not possess any mind. The source of order for the plants is the sunlight, which is, unlike heat, an ordered form of energy. But how could life originate in the absence of mind or just human—or even animal—nature? I believe that the formation of multiple weak bonds is an example of purely chemical and, of course, mindless irreversibility. Each **new** weak bond in the course of prebiotic contributes to the overall coherence and adhesion of the system. Because it immediately rises the threshold of solidity of the system.

Taking another example, once a religion takes a canonical shape, it is extremely difficult to take it apart and rearrange: it is hold together by a large number of cross-references. Still, it is possible, as reformist religions demonstrate.

The weak labile bonds, like those governing the behavior of the cooked pasta, are the very beginning of the genesis of evolution. But this is not the whole chemical story, for which one should better look into chemistry. In a nutshell, strong chemical bonds are typically inert. They do not dissociate easily into disconnected atoms ($A-B \rightleftharpoons A + B$), which is highly unstable, but rearrange in such a way ($A-B + C-D \rightleftharpoons A-C + B-D$) that the overall change of stability is relatively small. If we were built with weak bonds only, we would dissolve in a bathtub. We can say that a strong bond is labile if the quartet-like rearrangement runs fast, which is usually done by a catalyst, whether in a social or biochemical system, by decreasing the transition barrier. In social X-systems the catalyst is what Hannah Arendt called *homo faber*, man the maker, the term Thom also used.

Similar to the chemistry of life, the social and political chemistry consists of the interplay between the weak labile bonds, which lock and break by the hour, and strong inert bonds of allegiance to family, tribe, institution, or party, which can nevertheless be broken in an act of exchange, exemplified by a love affair, divorce, treason, or just

changing employment. In spite of all declarations of individualism, the modern human is extremely unstable in social isolation, so that the true meaning of individualism is lability, not stability.

Can the immense and ever growing concentration of global capital prepare the soil for the seeds for Michael Flynn's cliology? Can a few world tribes inhabiting the small impoverished planet be a plausible future? Is the American Empire doomed to cede its position of domination to another empire? Words, words, words again. But the question mark is half the answer. Nothing like that has ever happened, but each possibility is an alternative stable state. Anything can happen. We have to understand that what is most probably going to happen is what can happen faster. Whether we can list all possible final states is an open question in an incomplete system of knowledge. I believe that we cannot, but I do not believe we can ever have a proof one way or the other and I do not believe we can have a proof that we can or cannot have a proof, etc. Aristotelian logic is novelty-blind. We can play, however, with a Lego set of building blocks, constructing and testing various alternatives for initial, final, and transition states, checking them against a partially ordered scale of stability for a line-up. This is exactly what Sci-Fi is doing, following in the steps of a chemist who plays various chemical scenarios and compares the configurations—stable and unstable—by energy.

Ulf Grenander has always been a keen observer of the world behind the windows and, as his books testify, a real connoisseur and navigator of Everything. In [1M], he and I (also in [1B]) made an attempt to try on the conceptual goggles of Pattern Theory and look through them into the past. Alas, vision, unlike sound, does not generate an echo. But we have all the time ahead. It is my impression that the skeleton of the past history can be clearly seen in the double-locked cupboard of the future, but the second key is available only to professional historians.

Next, I would like to summarize the main lesson extractable from cooking pasta and driving brushmobile. It seems that there is no connection unless we regard both cases as configurations covered by the pattern of irreversible non-equilibrium process. The two

processes themselves are strikingly different—mechanical movement and growth of complexity—but both require supply of energy to keep them off equilibrium.

In order to descend somewhat from the dizzying heights of abstraction, we need to point to the source of non-equilibrium for the primordial pasta, i.e. , the natural analog of shaking. I believe that this meta-shaking came from periodic change of tide, day and night, weather, and seasons that kept all slow chemical processes at a constant non-equilibrium because the position of equilibrium depends on temperature and concentration. This could be possible only if the rate of primordial chemical reactions was slower than the rate of the change of conditions. The situation can be compared with the contest of a hare and a tortoise moving back and forth between two points: they would never be side by side except for very short moments.

In the end, as an example of a **possible** alternative pattern of further long run course of history, I am submitting my strictly personal view. Please note the blocks of the mental configuration.

From the point of view of a chemist life originates because chemistry is slower than astronomy. Life evolves further because the slow rate of chemical reactions makes catalysis—highly selective acceleration of some of them—a powerful source of order. Life increases complexity because multiple labile bonds hold together large aggregates. Society continues the work of life in the same vein, with *homo faber* in the role of a catalyst and mineral fuel instead of sun. The next step is open to imagination. I personally believe that today man-made things are the dominating component of the new civilization, money shines as the eternal Sun, and the human being is more *faber* than *homo*, more enzyme than DNA. If the resources of mineral fuel are depleted, sun-powered Things have an evolutionary advantage over heavy, errant, and voracious humans who, with their liquid-filled heads, will remain as a source of chaos necessary for further adaptation through mutating social DNA. Biosphere, formerly dominated by life, then by social life, then by exploding ideas, turns into technosphere.

I wish to draw attention that what is stable today may not be stable at changing conditions. The fate of the brushmobile individualism strongly depends on the quality of the batteries and if you are low on energy, the king or a feudal lord may take you as a vassal. Or you are welcome to earn your pasta dinner as a laborer—if the nation's batteries are almost dead. The global change from monarchy and conformism to democracy and individualism was done on mineral fuel. At some stage of resource depletion the trend could be reversed.

Purely intuitively I see the ongoing concentration and consolidation of capital as the first stage of involution.

The guns speak when the national batteries are low, and when they speak the muses are silent, mathematicians work on weapons, and philosophers are hunkering down in the trenches.

CONCLUSION

A scattered array of talking points and a few making points amount to the following main **hypotheses**.

1. As the century of debates testifies, the traditional formal (axiomatically closed) physical and mathematical theories have little power over Evolving Complex Systems (X-systems) because such theories are devoid of the notion of **novelty**. The X-system changes while we speak and should be analyzed in terms of novelty and difference.

2. Understanding of an X-system in terms of novelty might be possible while a larger X-system remains stable.

3. Understanding of an X-system might be possible in a standard—but expandable—set of **ideograms** (generalized metaphors) that symbolize their most abstract properties.

4. The standardization of language and a consensus regarding the ideograms might be achieved by evaluating them along their complexity.

5. Complexity of the abstract space housing the X-system might be a more appropriate measure for an X-system than the complexity of objects and states. From this point of view, **evolution is expansion (or collapse) of the generator space**.

6. Configuration space of Pattern Theory is an example of an open space housing the structures from molecules to thoughts and with a measure of stability.

7. The main task in understanding X-systems is to shift the emphasis from thermodynamics to **kinetics**. This can be done, following the pattern of chemistry, by comparing alternative transition states.

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The advent of the Web is changing the playgrounds where ideas frolic, mate, and multiply. The Web does not make the landscape flatter, just the opposite: one can fall through the cracks in the constantly shifting and swelling geological maze. In order to get out of the crevice, one would need a tug of a crew of links. The Web, however, has a **kinetic** advantage: it brings you to a distant planet in a few clicks, and then it is up to you whether to dig in or immediately leave.

If the topic is X-systems, one can have nine lives and still be unable to catch up with the literature.

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Rusty bolt: <http://www.eleventwentyseven.com/rustednut.jpg>

MATLAB CODES for topological analysis of text and grammar extraction in complexity (<http://spirospero.net/complexity.htm>)

REMINDER: start the input string P with 'START' and end with 'END');

See <http://spirospero.net/Salt2.pdf> for use

=====.

pg2.m

%pg : gives lists of words as NAME,

%and LEFT and RIGHT neighbors;

%array sizes made repetitive for other purposes.

%Text should be preloaded as character %string P=char('abc', 'bad', etc.)

tic

zname=[]; z=1;

words=[]; W = P; wname=P; %wname contains all names with

%repetition

WW=[]; %comparison cell; compare W=P and wname=P

sw=size(W); sww=sw(1,2);

```
twd=' ' ; % twd is word template, gives empty word
```

```
    for k=1:sww, twd(k)=char(' '); end, t=twd;
```

```
%t is an array of empty words
```

```
words(1).name= char(t);w=0; m=0;
```

```
%empty initial array of names
```

```
lenW = length(W);           % number of words in text
```

```
for i=1: lenW, m=0; WW=W(i,:);  z=1;
```

```
    for j =1:lenW
```

```
        WWW=W(j,:); k=isequal (WW, WWW); %WWW is a comparison cell
```

```
            if k==1 & j>i,
```

```
                wname(j,:)=char(t); m = 1; %inserts a gap into text
```

```
                z=z+1;
```

```
            end,
```

```
        end, zname(i)=z;
```

```
end
```

```
res=length(wname); w=0;
```

```
for f=1:res,
```

```
    if isequal (wname (f,:), char(t)) ==0,
```

```
        w=w+1; words(w).name = wname(f,:);Z(w)=zname(f);
```

```

        end,

end

lnW = length(W)-1; lew = length (words); NL=1;NR=1;

words(1).L(1)= {'#'} ;

words(1).R(1)= {words(2).name}; % included words(1).L(1)={'#'};

for k= 1:lew, NL=1; NR=1;

    for j= 2:lnW,

        d = isequal (words(k).name, W(j,:));

        if d==1,

            words(k).L(NL)={W(j-1,:)};words(k).R(NR)={W(j+1,:)};

            NL=NL+1;NR=NR+1;

        end

    end

end

end

%display NAME

disp(blanks(2)'), disp ('WORDS-NAME'), disp(blanks(2)')

F=char('00');

for j=1:lew,F=num2str(Z(j));FF=words(j).name;

    disp(F),disp(FF)

```

```
end
```

```
%disp(blanks(2)) %for r=1:lew, disp (Z(r)),end
```

```
pgwrk %script to display L and R neighbors
```

```
toc; t=toc
```

pgwrk.m

```
%pgwrk displays LEFT and RIGHT neighbors; uses pigwork.mat
```

```
disp(blanks(2)), disp ('WORDS-LEFT'), disp(blanks(2))
```

```
f = char(words.name); lw=length(f);
```

```
for m=1:lw,
```

```
    A=words(m).L; %list of LEFT neighbors with repetitions
```

```
    A=deblank(A);
```

```
    CS=A;
```

```
    %%%%%%%%%%
```

```
    pigwork, %counts repetitions
```

```
    %%%%%%%%%%
```

```
    A=CS;
```

```
    wordsa(m).L=A;
```

```
end
```



```

for mm=1:(lw-1),

    S=wordsa(mm).L; QL=size(S) ; sl=QL(2)-1;

    SK=wordsa(mm).L(1);

    for k=1:sl,

        B=SK; D= wordsa(mm).L(k+1); SK=strcat(B,',',D); B=SK;

    end

    CAS=SK; CAS=strrep (CAS,',', ' '); DDD= char(CAS); disp (DDD),

end

%%%%%%%%%%%%%%

disp(blanks(2)'), disp ('WORDS-RIGHT'), disp(blanks(2)')

for m=1:lw,

    A=words(m).R; %list of RIGHT neighbors with repetitions

    A=deblank(A); CS=A;

    %%%%%%%%%%

    pigwork,%counts repetitions

    %%%%%%%

    A=CS; wordsa(m).R=A;

end

for mm=1:lw

```

```
S=wordsa(mm).R; QR=size(S) ; sr=QR(2)-1; SK=wordsa(mm).R(1);
```

```
for k=1:sr, B=SK; D= wordsa(mm).R(k+1);
```

```
    SK=strcat(B,',',D); B=SK;
```

```
end
```

```
CAS=SK; CAS=strrep (CAS,',', ' '); DDD= char(CAS);
```

```
disp (DDD)
```

```
end
```

pigwork.m

```
CS; CSS=unique(CS); lcs=length(CS); lcsc=length(CSS); c=0;
```

```
for s=1:lcsc, %base word
```

```
    c=0;%start count
```

```
        for k=1:lcs %comparison word
```

```
            if strcmp(CSS(s),CS(k))==1,
```

```
                c=c+1; %count
```

```
            end %of counting
```

```
        end %of checking and counting of CS(s)
```

```
    if c>1, % if c==1, do not change CSS
```

```

        cac=int2str(c); %converting into string

        D=strcat(cac,'-',CSS(s)); CSS(s)= D;

    end

end

CS=CSS;

ms.m

%mindset script: ms

disp('REMINDER: start the input string with "START" and end with "END"');

tic; space=char(160);

%PART1  NAME ; unique list UNAME of G for G.name,

A=cellstr(P); G=[]; Q=[]; LP=length(P);

uA=unique(A); luA=length(uA); zer=[];

    for m=1:luA,        count=0;

        for n=1:LP

            if isequal (uA(m), A(n)), count=count+1;

                if count>1, zer=cat(2,zer,n);end,

            end

        end,

    end,

```

```

end, %zer

    AL(1)=cellstr('START'); AL([2:LP])=A([1:(LP-1)]) ;

    AR(LP)=cellstr('END'); AR([1:(LP-1)])=A([2:LP]) ;

    UNAME=A; UNAME([zer])=[]; lg=length(UNAME);

%PART 2: L&R

all(1)=1; arr(1)=1;ALL=[];ARR=[];

for k=1:lg,    % NAME from ANAME /P

    a=UNAME(k); al=[]; ar=[]; % first neighbors; correct ends later!

    cnl=0;cnr=0;

    for j=1:LP %search for neighbor copy

        b=A(j); %br=AR(j);        bl=AL(j);

        if isequal (a,b)==1,

            al=cat(2,al,j); ar=cat(2,ar,j) ;

        end

    end

    NB(k).L=al; NB(k).R=ar; %#####unique L and R neighbor list

end

%PART3 copy count NAME, L&R

```

```

for s=1:k

    G(s).name=UNAME(s);

    zz=strmatch((UNAME(s)), A,'exact'); G(s).NQ=length(zz); G(s).AQ=zz;
    %%%%%%%%%%%

    X=AR([NB(s).R]); Y=unique(X); lub=length(Y);

    output=[]; numr=[];RN=[];

    for qq=1:lub,

        mtch=strmatch(Y(qq),X,'exact');

        lmtch=length(mtch);

        w= Y(qq);

        if lmtch>1,output=strcat(output,num2str(lmtch),'-', w(1),';', space); end

        if lmtch==1,

            output=strcat(output, w(1),';', space);

        end

        %output=strcat(space,output,num2str(lmtch),'-', w(1),';', space);

```

```

numr=cat(2,numr,lmrch);

wwr=cellstr(w(1));

wu=strmatch (wwr,UNAME,'exact'); RN=cat(2, RN,
wu(1));  %%%%%%%%%%%

end,

G(s).nr = numr;

G(s).R=cellstr(output);

G(s).ReN=RN;


X=AL([NB(s).L]); Y=unique(X); lub=length(Y);%#####

output=[];numl=[]; LN=[];

for qq=1:lub,

    mtrh=strmatch(Y(qq), X, 'exact');

    lmtrh=length(mtrh);

    w= Y(qq); %%%%%%%%%%

```

```

    if lmtch>1,

        output=strcat(output,num2str(lmtch),'-', w(1),';', space);

    end

    if lmtch==1,

        output=strcat(output, w(1),';', space);

    end

    numl=cat(2,numl,lmtch);

    ww1=cellstr(w(1));

    wu=strmatch (ww1,UNAME,'exact');   LN=cat(2, LN, wu(1));

end,

G(s).L=cellstr(output);%#####

G(s).nl = numl;

G(s).LeN=LN;

end % structure G.name/L/R

G(1).L=cellstr('START'); G(lg).R=cellstr('END'); %#####

```

```

%%%disp('Type dsgw to display output for comprehensive 10 column table of
G');

%%%disp ('Type dsgn to display output for narrow 5 column table of G');

t=toc;

tm=strcat('P = ', num2str(LP), ' G = ', num2str(lg), ' time','.',space, num2str(t)) ;

disp(tm);

```

cblr

```

%cblr  lists

%tic;

space=char(160);

CB=[]; CCR=[]; CCL=[]; %structure CB stores bonds and cats: CB.bond, CB.cat

g=1; gc=1;  gl=1;gcl=1;

for k=1:lg,

    L=G(k).nl ; M=G(k).NQ; R=G(k).nr; kgr=G(k).ReN; kgl=G(k).LeN;

    %BONDS

    lr=length(R);  ll=length(L); %

```



```

for j=1:lr,

    if ((M >=R(j)) & ( R(j)>=2)),CB(g).bond=[k kgr(j)];g=g+1;

    end ,

end

%CATS (i.e., categories or classes)

if lr>1, CCR(gc).cat=k; CCR(gc).catr=[kgr]; gc=gc+1;end

if ll>1, CCL(gcl).cat=k; CCL(gcl).catl=[kgl];gcl=gcl+1; end

end

%DISPLAY ADAPTED FOR TABLE FORMAT

% copy to document,find and replace ^p^p for ^p, convert to table,

% find and replace double spaces for single spaces, repeat until none found

lcb=length(CB); lccr=length(CCR);lccl=length(CCL);

disp(space)

disp( 'BONDS'),%prepared for 2-column table;

disp(space)

%for c=1:lcb, disp(CB(c).bond), end

```

```

%%%for c=1:lcb, disp(CB(c).bond), BB= strcat(G([CB(c).bond]).name);
disp(char(BB)),end

for c=1:lcb, disp (num2str(CB(c).bond)), BB= strcat(G([CB(c).bond(1)]).name,'+',
G([CB(c).bond(2)]).name); disp(char(BB)), end

    % for c=1:(length(CB)), disp(CB(c).bond), BB= strcat(G([CB(c).bond(1)]).name,
    '_', G([CB(c).bond(2)]).name); disp(char(BB)), end

disp(space)

disp('RIGHT CATs' ), %prepared for 4-column table;

disp(space)

for c=1:lccr,

    %%%%disp (CCR(c).cat),

    %%%disp(CCR(c).catr),

    CTR=G(CCR(c).cat).name;

    disp(char(CTR)),

    DCTR=[];lcatr=length(CCR(c).catr);

    for cr=1:lcatr, CTR=CCR(c).catr(cr);

    DCTR = strcat(DCTR,G(CTR).name, ';',space);

end,

```

```

    disp(char(DCTR)),

end

disp(space)

disp('LEFT CATs' ), %prepared for 4-column table;

disp(space)

for c=1:lccl,

    CTL=G(CCL(c).cat).name;

    %disp(char(CTL))%%%%%%%%%%

    CCTL=char(CTL);

    %%%%%%%%%%%

    DCTL=[];lcatl=length(CCL(c).catl);

    for cl=1:lcatl, CTL=CCL(c).catl(cl);

        DCTL = strcat(DCTL, G(CTL).name,',';space);

    end,

    disp(char(DCTL)),   disp(CCTL)

end

```

```
disp(space)
```

```
%toc;t=toc;
```

```
%CB ,CCL,CCR,CTR, CTL
```

dsgn.m

```
%dsgn displays data for a narrow 5-column table; convert text to table with MS-Word
```

```
for dp=1:lg,
```

```
disp(num2str(dp)),
```

```
disp(char(G(dp).L)),
```

```
disp(char(G(dp).name)),
```

```
disp(num2str(G(dp).NQ)),
```

```
disp(char(G(dp).R))
```

```
end
```

```
%script dsg : displays G for a comprehensive 10-column table
```

dsg.m

```
%script dsg : display data for a comprehensive table (redundant for common use)
```

```
%PART 4 : DISPLAY
```

```
disp('The output can be pasted into MS Word document and converted ')
```

```
disp(' into a comprehensive table of 10 columns ')
```

```
disp('ATTENTION: Remove empty lines before conversion')
```

```
disp('with: "find and replace ^p^p for ^p"')
```

```
disp('COLUMN HEADS: 1. Generator number in G; 2.left neighbors; 3. left  
neighbor positions in G;')
```

```
disp('4. occurrences of left neighbors in input P; 5. generator name; 6.  
generator positions in input P;')
```

```
disp('7. right neighbor positions in input P; 8. occurrences of right neighbors in  
input P;')
```

```
disp('9. positions of right neighbors in G; 10. right neighbors;')
```

```
%if DT==1,
```

```
for dp=1:lg,
```

```
%FOR COMPREHENSIVE TABLE, 10 column
```

```
%1
```

```
disp(dp) %NAME ordinal number
```

```
%2
```

```
disp(char(G(dp).L))
```

%3

disp(G(dp).LeN)%%%%%%%%%

%4

disp(G(dp).nl)%%%%%%%%%

%5

disp (char(G(dp).name))

%6

disp (G(dp).NQ)

%7

disp ((G(dp).AQ'))

%8

disp(G(dp).nr)%%%%%%%%%

%9

disp(G(dp).ReN)%%%%%%%%%

%10

disp(char(G(dp).R))

end

% for dp=1:lg, disp(char (G(dp).name)), end;

% for dp=1:lg, disp(G(dp).QN), end;

```
% for dp=1:lg, disp(G(dp).AN), end;  
  
% for dp=1:lg, disp(G(dp).nl), end;  
  
% for dp=1:lg, disp(char (G(dp).L)), end;  
  
% for dp=1:lg, disp(G(dp).LeN)), end;  
  
% for dp=1:lg, disp(char (G(dp).R)), end;  
  
% for dp=1:lg, disp(G(dp).ReN), end;  
  
% for dp=1:lg, disp(G(dp).NQ), end;  
  
% for dp=1:lg, disp((G(dp).AQ)'), end;  
  
% [1:lg]' %line numbers  
  
%end
```

[email](#)

Yuri Tarnopolsky

PATTERN CHEMISTRY OF THOUGHT AND SPEECH
AND THEIR HYPOTHETICAL ANCESTOR



2010

Rough draft, often revised

PATTERN CHEMISTRY OF THOUGHT AND SPEECH

by Yuri Tarnopolsky

SUMMARY

The parallel between linguistics and chemistry has been drawing attention since the discovery of the DNA's structure and its ability to carry a protein "meaning." Besides, chemistry uses a particular language (chemical nomenclature) to convert complex non-linear structures into a linear word which can potentially be communicated through speech.

The present e-paper continues an investigation of thought, language, and conversion of one into the other within the framework of Pattern Theory of Ulf Grenander. This mathematical theory studies structural complexity regardless of interdisciplinary boundaries. It reduces structure to a set of atomic entities selectively connected by bonds, thereby representing observable objects of widest variety, including language and thought, quite like a generalized chemistry. The unusual aspect of Pattern Theory is its metrics which allows for distinguishing between more and less stable structures. Pattern Chemistry focuses not so much on stable structures as on the fleeting transition states between them, similarly to the way chemistry treats molecular transformations, making distinction between fast and slow transformations.

The central ideal of Pattern Chemistry is that complexity in nature and society evolves from simple states changing by simple steps.

Unlike speech, thought is not observable. The paper further explores a hypothetical protolanguage, called Nean, in which the simple elementary thought consisting of two connected entities directly translates into the simplest elementary phrase consisting of two words. Nean sounds like a repetitive random series of elementary doublets. Two doublets with common element can be combined into linear triplets. The paper explores the ability of this inherently both linear and primitive language to express more complex non-linear thoughts by means of the process of linearization. It appears that Nean, subjectively, is quite expressive.

A computer simulation based on simple principles represents thinking and speech as a competition of alternative thought structures for a spot in consciousness and further generation of linear speech-ready expressions longer than elementary doublets. The story of Three Little Pigs serves as the substrate of the process. The potential of Nean for further complexification and grammaticalization is discussed. Nean is regarded as a point of divergence between thought and speech and origin of the variety of grammars.

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Last updated: November, 2010

1. INTRODUCTION

This e-paper continues an exploration of Pattern Theory (Ulf Grenander) as generalized chemistry. My previous e-publications are listed in [complexity](#), see **APPENDIX 1**. They are duplicated on [SCRIBD](#) and could be found at some [other](#) sites on the constantly eroded by the flow of time Web. Referred authors can be also found through Web search.

As there was a common ancestor for humans and apes, there could have been one for thought and speech. How would it sound? What is the difference between thought and speech and, if there is any, how could they have diverged in evolution?

Unfortunately, the sounds of ancient speech cannot be heard. As for thoughts, although it is fortunate for all of us that we cannot “read” or “hear” them, it does not help us with understanding what thought is. By thought we typically mean the content of a verbal expression. Sometimes, however, we are stumbling at expressing our own thoughts.

Turning to origin of language, we must disregard written language and refined educated speech without which Chomskyan analysis would make but a few short steps. For most of history, even after invention of writing, the vast majority of people were illiterate.

I assume that thought and speech are essentially different. Until we decode thoughts, we may not know the truth, but I point to the fact that two people speaking very different languages seem to think in the same way because they can communicate their thoughts in a third language. Did thinking of an immigrant from Russia, like myself, change after abandoning the native language environment and switching to English? After a few years in America, I suddenly noticed that **in my spontaneous thoughts** people from my Russian past, who did not know a word of any foreign language, were speaking English. I am also certain that thinking of a chemist or a fan of music can be mostly non-verbal. I realize that I have no proof of either assumption because I cannot open my mind for the reader. But can I at least **speak** my mind?

I have been interested in those questions for a very long time. The central idea took shape around 1980, which coincided with my discovery of strikingly “chemical” Pattern Theory.

I was greatly influenced by (1) Ulf Grenander’s work on GOLEM ([Patterns of Thought](#)), which I was lucky to watch closely, and (2) the development of the concept of transition state in organic chemistry, which coincided with my years as a graduate student. Some other major influences are:

- (3) Manfred Eigen's concept of chemical evolution (since 1971);
- (4) The Heraclitean world of novelty (further explored by Ilya Prigogine), as opposed to the logically closed world of Aristotle;
- (5) Bourbaki's exotic concept of the [scale of sets](#) (rarely, if ever, remembered),
- (6) Ross Ashby's ideas of stability and homeostasis (remembered, but not appreciated).
- (7) René Thom's idea of most abstracts patterns of change (first abandoned, recently revived, especially by linguists).

My major factual sources are decades of life in both Soviet and American systems, linguistics of dissimilar languages, and the overall history of artificial intelligence and science of complexity, the infancy, promise, and missteps of which I observed live.

Although I am putting forward the **simple** idea that complexity is in fact an evolving **simplicity**, to elaborate this thesis would require a lot of words. I focus here only on some preliminary results, omitting most of the preamble, which can be found in [complexity](#). Occasionally I will embed some digressions, as for example:

SOME PRINCIPLES OF PATTERN CHEMISTRY

1. Pattern chemistry is representation of the world in terms of elements and bonds. It is indifferent to the specificity of areas of knowledge, putting on equal basis molecules, thoughts, social and economic phenomena, and anything else having a structure. It lies **within** the much larger domain of Pattern Theory and uses it as a conceptual platform.
2. Pattern chemistry borrows general ideas of Pattern Theory and combines them with the chemical concept of transition state: stable configuration **A** changes into stable configuration **B** through an unstable transition state [**A**, **B**]. The transition state is irregular in the sense of Pattern Theory.
3. Pattern chemistry is a study of exsystems—evolving complex systems. The chemical contribution to the problem of complexity is: **complexity evolves from simplicity in a sequence of simple steps**. If this statement evokes the idea of algorithm, there must be something to it, only without either the programmer or the computer.
4. Pattern chemistry is not supposed to have a closed set of axioms. It places on the foreground the little explored phenomenon of **novelty** (see [The New and the Different](#)). King Solomon was, apparently, the first neologist, of a negative type.

Exsystems are unique, large, naturally (i.e., slowly and spontaneously) evolving systems **open** in both thermodynamic and logical sense. They change while we speak about them, thereby challenging Aristotle and hailing Heraclitus. Generalizing the paradoxical Greek idea discussed by Aristotle in *Ethics*

(“Nobody can be called happy until he dies,”) the history of the exsystem is its only explanation, never complete until the exsystem is out of existence, leaving only the shells of its patterns.

The inherent openness of exsystems to novelty requires a decisively open mind from a natural scientist because it pulls the rug of theoretical solidity from under the feet and a possible grant together with it. You cannot promise knowledge, only understanding.

I distinguish between **artificial Artificial Intelligence** and **natural Artificial Intelligence**. The former is (1) designed, like a machine, for a specific function, (2) trained, tuned, and managed by human mind and therefore (3) “infected” with ready-made human knowledge. The natural AI is supposed to be launched by human mind as a primitive embryonic system with no specific function and then abandoned by its creator to feed, grow, and seek fortune on its own. The important idea behind this distinction, applicable also to Artificial Life, is that very simple systems can come to being by accident, while complex systems never can. Simple acts do not need a creator.

NOTE: In the previous paragraph I did not intend an allusion to the Bible. I realize, however, that there is a **pattern**: the natural AI shakes off the blissful somnolence after the first bite of knowledge.

Characteristically, the origin of life used to be a very troubling question for physicists who considered life mathematically improbable (was Gödel’s proof ever probable?) , but it is only a technical problem for the chemists whose daily bread is stepwise synthesis of new and never seen before complex molecules from simple ones.

If all this sounds rather grandiloquent, it may be justly disregarded. I am going to present here some synthesized thoughts, which, I believe, have some relation to natural ones.

I have to forewarn that I think and see the world as a chemist, which may be very different from the way other people do. My computer “experiments” are neither true experiments, nor computer models, nor simulations in the area of thought and speech. To be exact, they are just illustrations of my own thinking.

2. THE NEAN LANGUAGE

What happens when a two or three year old child listens to an illustrated book “*The Three Little Pigs*” read by a parent?

There was an old sow with three little pigs and as she had not enough to keep them she sent them out to seek their fortune. The first that went off met a man with a bundle of straw and said to him, “Please, man, give me that straw to build a house.” Which the man did and the little pig built a house. Presently came along a wolf and knocked at the door and said, “Little pig, let me come in.” The pig answered, “No.” The wolf then answered to that, “Then I’ll puff and I’ll blow your house in.” So he puffed and he blew his house in and ate up the little pig.

The child might have never seen live sow, piglets, straw, and wolf. Some words, such as “poor” or “fortune” could be just sounds of parental babble. While animals and things are represented by pictures, some actions may be rendered only by words. One of them, like “blow” may be familiar from blowing soap bubbles, others, like “send away” may not.

Let us further modify the situation by placing the child inside a cave where ancient humans are right in the process of developing intelligence and mastering language. They are telling stories to children and each other. How could their language sound in *situ nascendi*? What trace does the story leave in the previously empty mind? What is the difference between thought and speech? How could this difference emerge?

While approaching those questions a few years ago, I called the hypothetical primitive language Nean. The name Nean honors the Neanderthals, but does not imply that they were speaking it or speaking at all. I believe, however, that early humans did, as does a two year old child, who “combines words into a short sentence-largely noun-verb combinations” and only by the third year strings together at least three words.

CONCEPT OF RECAPITULATION

Although the universality of the concept of recapitulation—repetition of evolutionary stages in individual development (“ontogeny repeats phylogeny”)—has been disputed, its general validity is widely recognized. In terms of pattern chemistry, recapitulation means that the pattern of complexification could be the

same in all exystems. In terms of embryology it may mean that the order of the evolutionary path is partially recorded in the individual genome. We can say this about a pattern, not configuration. Individual human life in modern society is an example of exystem, too.

Nean consists of single words (singlets), doublets, and, at most, triplets. Unlike modern developed languages, which convert the often branching, non-linear, fuzzy, and meandering thought into a linear speech along convoluted grammar rules, Nean is straightforwardly linear and, I suggest, allows us to literally hear the thoughts which do not depend on any modern or primitive language. Nean opens a window into thinking not obscured by the complexity of modern language, which overwhelms even some heads of states. It is not infected either with intelligence or with ignorance. Nean is the language of simplicity, not complexity. Its chemical flavor consists in a potential for unlimited complexity in further evolution.

The closest “adult” approximations to Nean are pidgin languages and early stages of mastering a foreign language by adults.

At the opposite end of the scale of complexity we find the language of philosophers and most writers, as well as scientists, which would be impossible without writing and ability to keep long strings of words on paper or computer screen for an indefinite time, all the more, edit them.

SIMPLICITY IN NATURE

Simplicity means building complexity from a simple beginning through a sequence of very simple steps fitting a limited number of patterns. Related mathematical objects are recursive functions, complete mathematical induction, and, especially, fractals. The entire enormity of chemical structures, from many monomeric natural components of plants and animals to the monotonous complexity of biopolymers, consists of simple elements and can be generated by simple operations of synthesis, predominantly, within the environment of a single atom or two, and essentially reduced to breaking or locking up a few bonds.

Organic chemists, as also, probably, architects, strongly prefer visual perception to verbal communication. As a chemist, I favor demonstration over explanation. **Figure 1** presents three substances found in plants. Chemists place them all in one class: terpenes (from *turpentine*). Terpenes and their derivatives terpenoids (e.g., camphor, menthol) form a wide, motley, and nice smelling variety, see [Gallery](#). What can they have in common and how could plants be so chemically sophisticated as to produce them?

The carbon skeletons of terpenes (and natural rubber) are built of the same relatively **simple** isoprene unit : five carbon atoms with a fork at the end. They are all related by chemical origin and properties and can undergo dramatic, dizzying rearrangements of their skeletons which turn one terpene into another. Steroids,

produced by both plants and animals, have the same isoprenoid regularity of the skeleton. A single simple principle explains the diversity and its origin in nature. To borrow Richard Dawkins' metaphor of Blind Watchmaker, the nature, having once invented a single isoprene gear, found a way to all terpene and steroid "clockworks," some of which endow humans with the joy of sex.

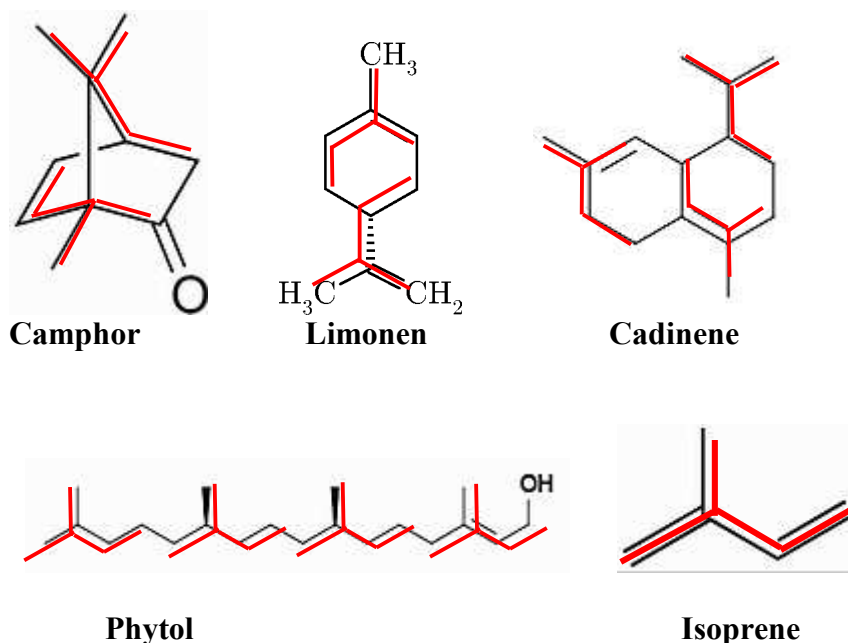


Figure 1: **Simplicity behind complexity.** [Terpenes](#) are a richly diverse class of natural components of plants, all built of the same isoprene unit

From pattern-chemical view, both thought and language emerged from the once invented single connection in the nervous system: **A—B** .

I want to draw attention to the essence of pattern perception of the world: it transcends the borders between disciplines of knowledge and different domains of reality. The molecular chemistry of terpenes and steroids is of no significance whatsoever for linguistics and *vice versa*. When, amazed by the richness and diversity of the world, we try to understand how **it all** is related and how **it all** was "created," we need some vantage point from which **it all** can be seen. This point has always been in the realm of poetry as art and is what Pattern Theory offers as science.

3. LINEARIZATION: FROM THOUGHT TO SPEECH

Nean starts with the smallest nuclear particle of complexity: a bonded pair.

I translate the pig story into the “classic” doublet (two-word phrase) dialect of Nean:

Sow is **old**. **Sow** has **pigs**. **Pigs** are **three**. Their names are: **First** is **pig**. **Second** is **pig**. **Third** is **pig**. **Sow** is **poor**. **Sow** **sents**. **Sents** **first**. **Sents** **away**. **Sents** **seek**. **Seek** **fortune**. **First** **meets**. **Meets** **man**. **Man** has **bundle**. **Bundle** of **straw**. **First** **says**. **Says** to **man**. **Man** **give**. **Give** **straw**. **Give** to **First**. **First** **builds**. **Builds** **house**, **Wolf** **comes**. **Comes** to **house**. **Wolf** **asks**. **Asks** **First**. **Asks** to **enter**. **First** **says**. **Says** **no**. **Wolf** **blows**. **Blows** **house**. **Wolf** **eats**. **Eats** **First**.

I have added some words and endings in small print just to illustrate what Nean ignores, but I will further do without them, like the standard written Hebrew and Arabic do without vowels.

Nean is understandable not from a podium but in a context of a concrete situation. Its only rule of grammar is that the doublet can be ordered, so that **first** ask and ask **first** may have different meanings in a particular local dialect of Nean.

I advise considering words of Nean simply as symbols, and I would prefer pictograms

like    to English words. Ideograms, like the Chinese 狼, wolf, 猪, pig, 男 man (male, “the one who toils in the field”), and 福, fortune, are even better because they are mind-sterile for a non-speaker of Chinese. Numbers are the best, but only for computers talking to each other. I will use English words instead of numbers, although my computer program operates with numbers assigned in a particular order, which I will further describe.

The phrases of Nean are singlets, doublets (“classic, pure” Nean) to which the “Late” decadent Nean adds triplets. The triplets are formed by a transformation rule which is a kind of “pattern-chemical” reaction:

wolf—eat + eat—first → wolf—eat—eat— first → wolf—eat— first

Triplets and doublets can be further **polymerized** into longer phrases, but what for with no **time** on a hunt or too much of it in a cave? If you get used to Nean, it sounds remarkably expressive and quite capable of nurturing its cave Hemingway.

COMPLEXITY OF LANGUAGES

In post-Nean era, agglutinative languages (like Latin and Russian) acquired a freedom of word order, which they much later used for expressing fine, even redundant, nuances of speech. Probably, all languages at an early stage were synthetic, richly inflected and complicated, as opposed to analytic ones. The Old English was more complex and had a looser word order than the modern English, the Old Church Slavonic was even more complex than Russian, and Sanskrit was much more intricate than its posterity.

Why could complexity of language, supposedly, evolve through an explosive growth and then subside is an interesting question. I believe the answer might be found in the hypothetical area of linguistic thermodynamics, which would approach language evolution as any natural process (not a completely new idea after all principles of economy, least effort, etc.). General laws of nature are the only reliable guides into extinct past.

We access extinct languages through their **written** fossils. Writing is a natural jungle-like habitat for complexity. Tribal polysynthetic languages, like the Navajo, which beats all records of complexity, typically developed in relatively stable, insulated, or widely dispersed types of environment (large planes, mountains, islands) in tribal societies with little mixing. A writer is also a loner, as compared with the buyer-seller pair at the marketplace. We can only speculate about the evolution of linguistic complexity, however. Some new insights into this problem could come from studying the relative complexity of language, i.e., the ratio of complexity of language to socio-economic complexity, taking to account the socio-economic temperature. We might find then enough simplicity in Navajo and the Inuit dialects.

Of course, I express my opinion not as a linguist, but as a pattern chemist. The keystone principle of pattern chemistry, formulated only in 1970's (Ilya Prigogine) is: the processes in living nature, human history included, are radically different from the processes in inanimate nature. The exsystems (organisms, societies) stay far from equilibrium, while natural inanimate systems are either as close to it as possible under circumstances or slowly moving toward it. Besides, ethnic mixing, the pattern counterpart of physical heat and chemical stirring, destroys stagnant communities and any melting can only simplify a system.

Probably, the principle of stringing words together, invented with Nean, turned out too successful: everything on hand was glued together. Here is an example that fascinates me, see **Table 1**.

Among blue objects, in Russian, **flag** is masculine, its English equivalent of personal pronoun is **he**. Sea and sky are neutral, it, and cup is a **she**.

Table 1: **Parallelism of personal pronouns and adjectives in the Russian language.**

English	Russian: declension of “he” and “blue flag”			
he	on (he)	siny flag (blue flag)	он	синий флаг
to him	y mu	sin mu flagu	е му	син ему флагу
about him	o nem	o sin em flage	о н ем	о син ем флаге
with him	s nim	s sin im flagom	с н им	с син им флагом
without him	bez nego	bez sin ego flaga	без н его	без син его флага

Why in the world should the endings of **adjectives** copy the endings of **personal pronouns**? I see it, half-seriously, but not half-jokingly, as a relic of Nean:

English: I go to blue sea

Classic Nean: I-go **go-to** to-it **it-to** to-it it-blue blue-sea **sea-to** it-blue **blue-to** to-it.

For some reason, the spoken language tends to eliminate the doubling of syllables in words. This phenomenon is called haplology (“saying a half of it”), which the term itself illustrates: haplology. Haplology of “haplology” would produce “haplogy,” but writing preserves the longer form of an exotic word. If “haplology” were a common fruit, it would collapse into “haplogy.” Probably, a longer word takes more time to say and this is why a compressed version wins the competition with the longer one: it is, in chemical parlance, more **stable**, or, in physical parlance, has lower energy, and, in pattern-theoretical parlance, is more probable.

Evolution of language, as any natural evolution, is a never-ending walk to resting places of stability through the rough and uncertain terrain of transition states. This, of course, is only a hypothesis and we have to wait for somebody to develop thermodynamics of spoken language to see if it makes sense. It certainly makes as much sense to say **wolf-eat-first** instead of **wolf-eat-eat-first** as to say **laundromat** instead of **laundry automat** even if you are not in a hurry.

REDUPLICATION

Accidental doubling of syllables in haplology does not carry any semantic or grammatical load. On the contrary, **reduplication**, which on the surface is the

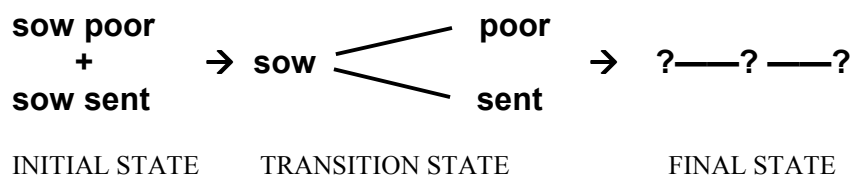
same, carries a function. It can be an expression of plural, as in Indonesian (*orang-orang*: people), or of a some special degree of quality, as in emphatic colloquial Russian (*bely*, white, *bely-bely*, perfectly, amazingly white, *idet*, walks, *idet-idet*, walks for a long time, especially in folklore) or standard Thai (*uan*, fat, *uan uan*, very fat). So, regarding the pig story, **eat-eat** could be retained for expressing either speed of eating or its shocking cruelty.

Nean is the language of thought in the sense that it expresses the thought directly by an ordered linear string of words. More exactly, Nean preserves the **topology** of thoughts, so that the speaker literally speaks his mind. There is, however, an important and instructive chemical complication when we attempt to linearize doublets into triplets.

How can we combine, compress, and line up the thought represented by the following pairs of doublets or even all four of them?

sow poor , sow sent or sent away , sent seek

Between the initial state of the thought consisting of two doublets and the final linear triplet of speech lies the nonlinear—because of the word order—transition state.



We cannot linearize it by the rules without either reversing the word order (**poor sow sent** or **sent sow poor**) or breaking up one of the doublets (**sow poor sent** or **sow sent poor**).

This is exactly the point at which the evolutionary ways of thought and speech must diverge.

Thought is a state of mind, a mixed bag (not the “bag” of set theory) of singlets and doublets (can of worms is a better metaphor). There are different ways of linearization and different languages deal with the problem differently: **sow poor sent** can be standard in French (*La truie pauvre a envoyé le cochon*), and **poor sent sow** is not good, but still possible in Russian, something like: “Disappointed, went she home.” Isn’t it possible to say in English, “School is almost done! Oh, so happy away we go to college?” We are so **excited** (abstract temperature of thinking is high) that we do not care about grammar anymore: the rules melt down. Neither a natural process nor an artificial one is possible without change in energy or entropy or sensitivity to temperature.

Regarding the mind, we deal there with configurations and patterns which cannot be pored from a bottle and put into a flask, like chemicals, in zillions of tiny copies. We cannot talk about symbolic transformations, which I call “thinking,” in exactly the same manner as about molecular transformations. They are not dynamic systems in physical sense. Events in exsystems are Heraclitean: singular and happening only once through the timeline. Ilya Prigogine formulated this property, controversially, but neatly, as indeterminism, not in quantum-mechanical sense, of course.

Our pattern-chemical explanations by necessity are rather metaphoric and not rigorous, but to what exactly degree is an important separate topic which I am not yet prepared to systematically approach.

ENTROPY AND INEQUALITY

To give some hints, we cannot chase probabilities in unique and singular acts, with no actual statistical observations. Entropy without probabilities is hot air, even though initially it was a macroscopic thermodynamic parameter of hot air. We ask what entropy is and hear “uncertainty.” We ask what uncertainty is and hear “entropy.” This is why I, under an approving look of Aristotle, attempted to purge entropy from pattern-chemical language in *Introduction to Pattern Chemistry*, substituting **inequality of distribution** for it. For our purpose, Jini coefficient is fine, even though it does not bring a dime. It does not take it away either.

In the language of “simple reasons,” the non-linear transition state is a higher barrier to speech simply because it takes time to make a choice. While the hunter is thinking how to warn his partner about a saber-tooth tiger, the unthinking tiger will come to instinctive decision much faster. Politicians, expected to be tigers, usually pay small political cash for “dithering.”

The direction of the post-Nean evolution of language splits: one route goes toward long-distance fixed word order or affixes (Velcro fasteners between words), the other leads to the fixed word order and shorter sentences to preserve it. In pattern-chemical terms, both offer **catalysts** for linearization of thought. Grammar is a typical catalyst: it can be used again and again without losing its properties, while slowly evolving further, most probably, toward simplification, until literacy brings its evolution to a halt (and texting pushes its further).

However simple it is, the Nean has an obvious potential for increase of complexity.

Simple thoughts: first meet. meet man. man bundle. bundle straw.

Composite thought: first meet man bundle straw.

Synthesis of modern speech as linear composition:

first meet-s a man with + man with a bundle of (something) + bundle of straw

→ **first meets a man with a bundle of straw.**

“**First meet man bundle straw**” is still Nean, but on the way to complexity. The original simple doublet Nean version looks understandable enough, but I am afraid to infect my model with human predilections. With all the precautions regarding sterility, objectively, I can see that the chain of four doublets “**first meet, meet man, man bundle, bundle straw**” is longer than the single quartet “**first meet man bundle straw**” but the linearization is straightforward: the speaker of Nean has only to **speak his mind** to be understood in context.

It is different with the poor sow. The synthesis (“de-duplication”) produces a non-linear thought, **Figure 2**.

After the **de-duplication**, the non-linear configuration still must be linearized some way. This is how diverse grammars emerge and those which ensure more stability at the marketplace win.

My intent, however, is to stick to Nean and try to extract as much linearity from it as possible. As a chemist, I want to fill up a beaker with words and see what kind of chemical reaction can happen between them and whether I can get any composite thought from the mixture without the germs and enzymes of my own language and intelligence. The computer illustrations, therefore, consist of three parts: **LISTENING** (filling up the beaker), **THINKING** (mixing and linearizing), and **SPEAKING** (generating linear output). The graphic output will even look like a beaker.

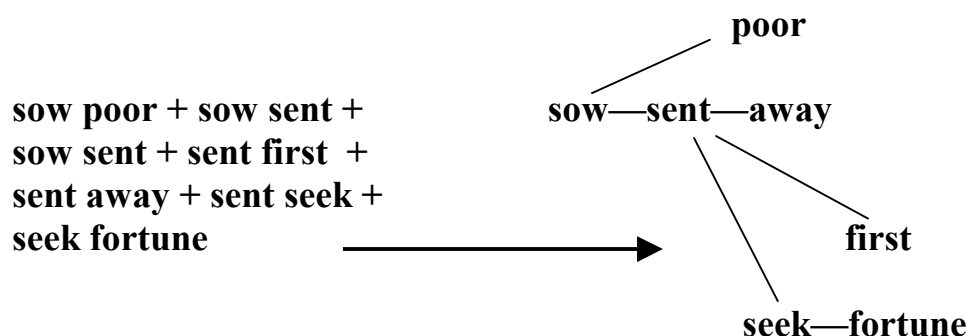
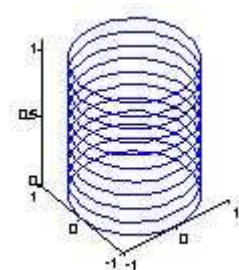
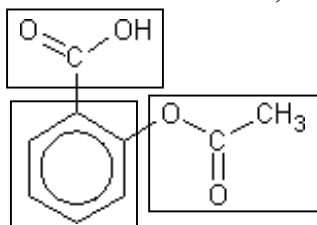


Figure 2: Synthesis of non-linear thought

I do not know for sure whether what I call listening, thinking, and speaking has anything to do with the human functions of the same name, but I believe that there is a way to find out.

I do not think that language is absolutely necessary for thought. I want to give a personal account regarding non-verbal thinking of a chemist and I start with a simple illustration.

Chemistry is a headache for most normal people. This is why I take aspirin as an example. When I think about it, I imagine its chemical structure. It is shown in the figure.



Aspirin

Nevertheless, I do not mentally see the whole picture, although I can draw it. I see the three major components of the molecule—benzene ring, carboxyl, acetylated phenolic hydroxyl, and the way they are arranged around the ring. I can **say** what is in the formula: 2-(acetyloxy)benzoic acid. It sounds “two-acetyloxy-benzoic-acid”, which is, actually, a phrase composed with a standardized dictionary and grammar developed by chemists for communication between

themselves. Any organic chemist will understand me, although probably surprised that I do not say simply “aspirin.” **Frequently used** chemical words are all shortcuts and not chemically correct names.

I see the process of verbal “expressing” the structure of aspirin as a linearization of non-verbal thought. Moreover, when I write the structure, I perform a dimensionality reduction: I translate the actual 3D structure, not shown here, into 2D picture. I cannot give an exact account of what is happening in my head when I think about aspirin (if not I, then, for sure, nobody can), but I certainly feel it as an assembly of some fragments and features of structure, whether verbal or visual.

LINEARIZATION IN CHEMSPEAK

Figure 3 presents a more complicated example. Atorvastatin Calcium (Lipitor) has the chemical name (3R,5R)-7-[2-(4-fluorophenyl)-3-phenyl-4-(phenylcarbamoyl)-5-propan-2-ylpyrrol-1-yl]-3,5-dihydroxyheptanoic acid, calcium salt.

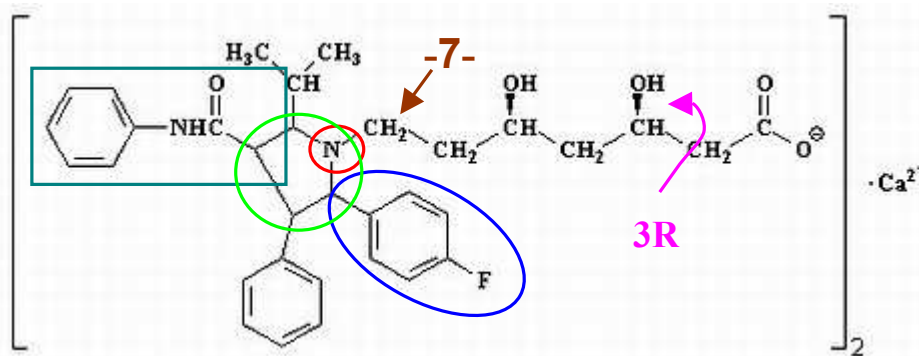


Figure 3: Brain surgery of Atorvastatin Calcium

The name is not even a word but a whole detective story. The tong-twisting language makes the name difficult to pronounce, but a chemist understands **the picture** faster than you can say “Jack Robinson.” I am not sure, however, that more than a handful of chemists can **say** it if wakened up at 3AM.

When I **think** of the structure, not just stare at it, I have in my head a soup of fragmentary thoughts **in no particular order**: “fully substituted pyrrol in the center” “4-fluorophenyl,” “phenyl,” “isopropyl,” “*ω*-*dyhydroxyheptanoic acid* (not a correct chemical expression) at pyrrol’s N,” and other finer details, mostly non-verbal, including the order of substituents. I show **by color** the correspondence between some fragments of the name (morphemes) and the elements of structure which they designate.

Anybody can now find **5R** in the formula. Another test for a non-chemist: find **phenyl**. Most probably, you will find yourself thinking non-verbal, except for the word **phenyl** sounding in your head (perhaps not even sounding).

It is the **grammar** imposed by [International Union of Pure and Applied Chemistry](#) which orders my thoughts about the structure and guides me through packing them into the long chemical name, if I need to do that. I have to look at the structure for that because it is too big for my visual memory. As for the fluorine (F), I feel an instinctive aversion to fluorine in drugs, water, and toothpaste. I refuse to take Lipitor and prefer a totally different Simvastatin. This is how my thoughts, either visual or verbal or irrational, guide my behavior. The structure of Simvastatin, by the way, invokes memories of my very first postgraduate work on one of its fragments (lactone ring) and starts a new chain of thoughts far away in time and place from statins.

Spoken language is not the only way of expressing a thought. Gesture, dance, ceremony, and picture are non-linear ways of communication, too, although some only one-way. Sound is not as restricted by environment as vision and speech and, unlike gestures, it does not impede work and movement. Writing definitely followed pictures until the divergence between letters, pictograms, and ideograms, which survived in Chinese and flourish in public signs. As to art installations—I am speechless and so should be you.

I am repeating these trivialities to put forward the non-linear origin of thinking. Thought could be much older than language and not limited to humans at all. What has been much less discussed is that the linear language ensures communication between humans and things and brings it up to speeds far exceeding natural human possibilities.

When thought lags behind speech, electronic economy collapses. Do we remember that the Great Depression happened in the era of telegraph, telephone, and ticker tape?



4. LISTENING

The following text is ready for entering as character strings:

'sow old' 'sow pig' 'pig three' 'first pig' 'second pig' 'third pig' 'sow poor' 'sow sent' 'sent first' 'sent away' 'sent seek' 'seek fortune' 'first meet' 'meet man' 'man bundle' 'bundle straw' **'first say'** 'say man' 'man give' 'give straw' 'give first' 'first build' 'build house' 'wolf come' 'come house' 'wolf ask' 'ask first' 'ask enter' **'first say'** 'say no' 'wolf blow' 'blow house' 'wolf eat' 'eat first'

There are 33 doublets in the text. I allow **'first say'** to occur twice, just to see what happens, but it is counted, inconsistently, only once in the array of words NAMES. What happens will be seen later, but I did not know it in advance.

There are 28 elementary words (singlets):

'!' 'sow' 'old' 'pig' 'three' 'first' 'second' 'third' 'poor' 'sent' 'away' 'seek' 'fortune' 'meet' 'man' 'bundle' 'straw' 'say' 'give' 'build' 'house' 'wolf' 'come' 'ask' 'enter' 'say' 'no' 'blow' 'eat' .

I call the simple algorithm of my “LISTENING” program “SCALE.” The name SCALE honors Bourbaki’s [“scale of sets”](#). SCALE adds combinations of set elements as **new** elements, remembers their composition, but, more importantly, SCALE has a primitive recognition function: it distinguishes between **new** and **old**. Its workspace WORLD (square matrix WW) initially contains only the “tohu-ve-bohu” (formless and empty) element '!'. The total number of elements (words) is, therefore, 62. Programs SCALE and, for “THINKING,” PROTO were first described in [Molecules and Thoughts](#) (2003).

In the subsequent illustrations, my input is in square brackets after “TYPE”. The rest is the output of the program. I initiate SCALE with typing `sc . start` initializes the workspace, but there is an option to `continue` filling up the previous one.

WORLD (WW) is a 62 x 62 connectivity matrix filled up in the order of the appearance of words in the text. The words are stored in NAMES.

>> [TYPE sc] sc

1 to start, 2 to continue [TYPE 1] 1

enter number of cycles (nn): [TYPE 2] 2

ATTENTION: Interspaced components should be entered
between apostrophes as single string of characters

press any key to continue [ENTER]

I start with the basic singlets and then load the doublets in the order of their appearance in the text. Command `link` processes a row of matrix `WW` and lists all words with the same element. Here is an example from the middle of the process:

enter components [TYPE 'sow old'] 'sow old' [ENTER]

This is new. Name it [TYPE 'sow old'] 'sow old' [ENTER]

enter components [TYPE 'sow pig'] 'sow pig' [ENTER]

This is new. Name it [TYPE 'sow pig'] 'sow pig' [ENTER]

If you want to check `WORLD` for a name, type: `link`

To see `NAMES`, type: `NAMES`

To display the 3D world, type `plotw`

```
>> link
NAME to check
[TYPE 'sow'] 'sow'
sow old
sow pig
```

```
>> link
NAME to check
[TYPE 'old'] 'old'
```

```
>> link
NAME to check
[TYPE 'pig'] 'pig'

>> link
NAME to check
[TYPE 'sow old'] 'sow
old'
sow pig
```

```
>> link
NAME to check
[TYPE] 'sow pig'
sow old

>> [TYPE] NAMES
NAMES =
!
sow old
sow pig
```

Note that the structure of `WORLD` retains the order of its genesis. I hint here to the idea of recapitulation, but I am still far from exploiting it.

`SCALE` detects the components of doublets, accepts and assigns a name to a **new** combination or classifies it as **old**. If the order of components in a **possibly new** doublet is different from what is in `WORLD`, `SCALE` remarks **Looks like W**, gives the coordinate of word `W` in `WORLD` and asks: 'Is it new? 1/0?'. `SCALE`, therefore, may reflect or disregard the order of components, which increases its universality.

In short, words , from singlets, to doublets, are connected in WORLD if they share a component. Examples:

sow—sow_old
sow_sent—sent_away
sow_sent—sent_seek
first_build—first_ask

For the purpose of visualization, all 62 words are arranged in a circle. A sequence of stages in building WORLD can be portrayed in 3D.

CRITERION OF INTELLIGENCE

One may note that I (or another operator, **educator** , as I would say) take part in building WORLD and in this way infect it with human knowledge. For example, the operator decides whether the order of components is relevant. This is true, but note that it is done in the manner of a dialogue. Whether education was right or wrong, good or bad, can be ultimately decided only in a socio-economic and intimate setting, not by the educator. AI, I am sure, can create a good model for dialogue, which is the ultimate criterion in much disputed Turing test, but EVE—I decide for the first time to call “it” by name—is born in a dialogue. I see a test of intelligence as the ability to achieve prolonged stable states **inside an exsystem**, not the ability to be taken for a human on the basis of email communication, all the more, texting. From this point of view, animals are intelligent, which is exactly my point. I do not measure intelligence, but simply look for its presence. Probably, it has already been suggested, but I have not found anything except Ross Ashby’s homeostasis. Is humankind intelligent? We need more time to think about it. (Answer: there is no such thing as humankind).

Figure 4 shows how SCALE connects the bond between **sow old** and **sow pig** because of the common component **pig** .

After the entire text is acquired, its internal representation looks like in **Figures 5 , 6 , and 8 . Figure 7** shows a (25:35) fragment of WORLD on both sides of the borderline between the first 28 singlets and the following (29:62) doublets. The singlets do not have any bonds until their entries into doublets appear **from the later doublets**, not toward them. WORLD takes heed of the arrow of time. It can look back, but not ahead.

New singlets can be acquired at any time, of course, and I placed them all in the beginning to imply that the listener to the story is already familiar with all words. This is not a necessary condition, however.

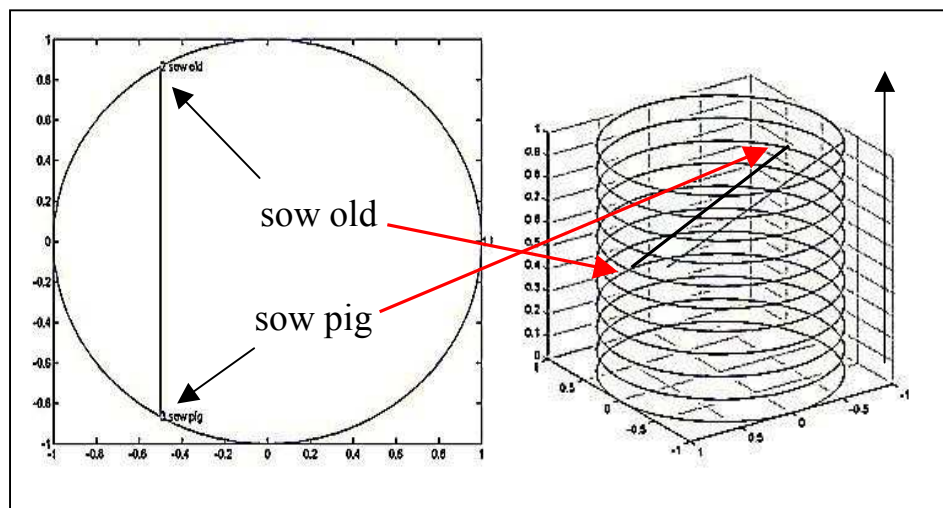


Figure 4: **SCALE** absorbs ‘sow old’ and ‘sow pig’. Timeline goes up.

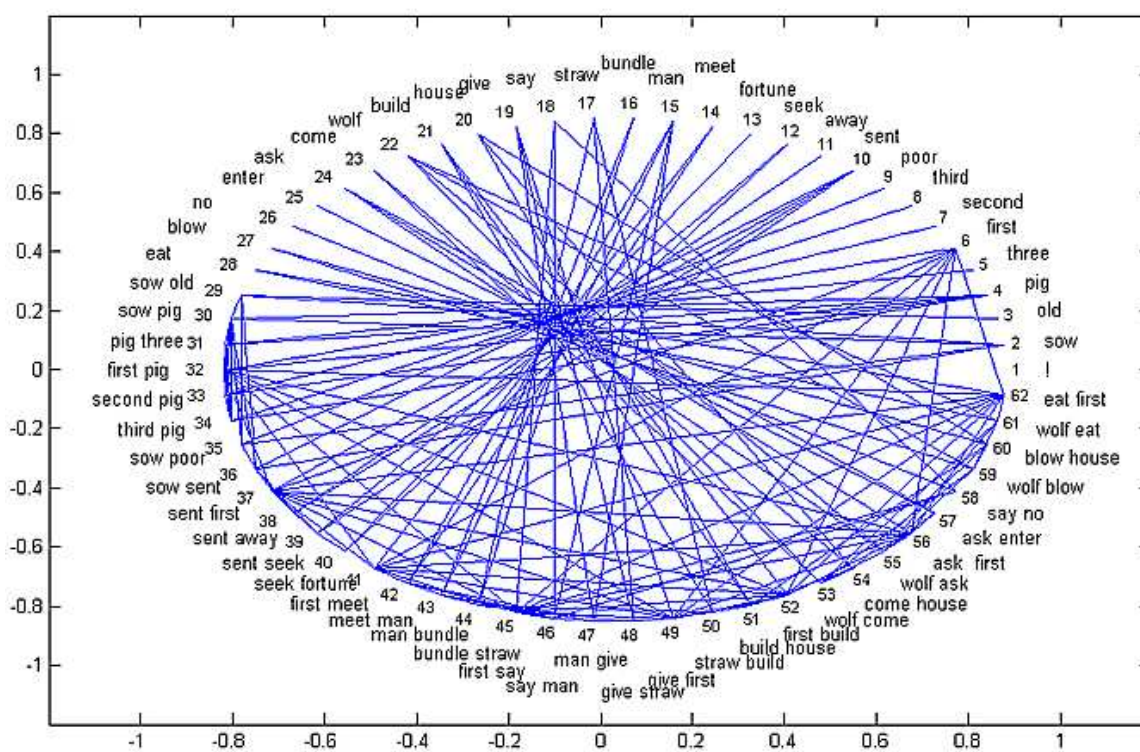


Figure 5: 2D view of WORLD.

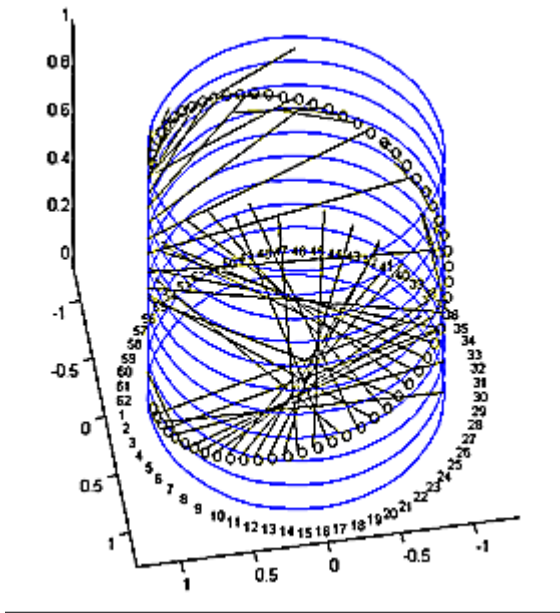


Figure 6: 3D view of **WORLD** ordered along the timeline of acquisition (axis Z)

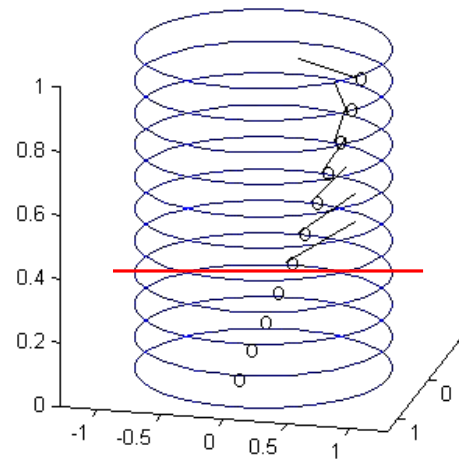


Figure 7: **Fragment WW(25:35)** in process of buildup and the border (red) between singlets and doublets

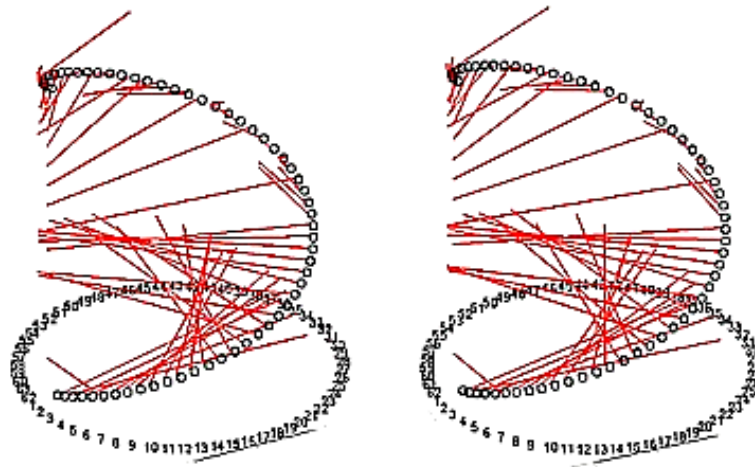


Figure 8: **Imitation of stereoscopic view of WORLD**

The **READING** stage can be extended indefinitely by adding new entries of **WORLD** on top of the old ones. Note, that during the **READING**, bonds go not from past to present, but from present to past. Therefore, the deeper and older areas of **WORLD** are being enriched by new bonds induced by new acquisitions.

Building of WORLD does not require operator's intelligence (it can be automated) and does not serve any utilitarian behavioral function typical for AI. It is not difficult to imagine further steps toward realism, however. Thus, in principle, WORLD can—and should—react to any external stimulus by activating SCALE. We can also impose gradual fading of old areas, if desired. Next, we make WORLD fractal in an irregular manner.

I am trying to design not a mind, however, but a possible launching pad toward its emergence. All I expect from the intellectual newborn is to start feeding on new experience and digesting the foodstuff. It is not learning in the sense the dogs and traditional AI systems are learning to bring you a pair of slippers. The only function of the model is to grow and think.

The model (or, rather, the seed of a model) outlined here needs a name. I confirm the name EVE because Eve was the first to taste the apple and she liked the taste.

5. THINKING

The next stage is the pattern-chemical process of “thinking.” It consists in generating a sequence of winners in a competition of singlets and doublets for, metaphorically speaking, ascent into “consciousness” in which, in our experiment, only one thought can be a star.

Consciousness is a serious business and I do not want any extra controversy. I call the selected or appointed thought **acton** and give it the star status marked by asterisk.

THINKING starts by designating the initial thought in consciousness, although it can be chosen at random. All next actons are selected along the probability distribution calculated before selection. The core of THINKING is a modified procedure **PROTO**, script **p3d3**. There are several versions of the unit **select** which calculates the probability distribution.

The selection of acton is based on a modified idea of the pioneering work of Manfred Eigen, initiated in the 1970’s and still progressing. It would take a lot of space to explain my choice of computation for the stage of thinking. Darwinism and neural realism are two of them. I can afford only a short digression.

MANFRED EIGEN AND MOLECULAR EVOLUTION

To say the least, Manfred Eigen’s ideas, inspired by Darwin, but essentially chemical, are so general that they have put roots in areas as different as origin of life and origin of language (Martin Novak). Moreover, the readers (and authors) of the avalanche of literature triggered by the Ising model of ferromagnetism belong under the same conceptual umbrella, probably, unaware of that, because the equations are, in principle, of the same type, better to say, **pattern**, as Manfred Eigen acknowledged.

REFERENCES:

- Leuthusser, I. (1986), An exact correspondence between Eigen’s evolution model and a two-dimensional Ising system, *Chem. Phys.*, 84, 1884-1885.
 Eigen, Manfred, The physics of molecular evolution; In: Molecular evolution of life; Proceedings of the Conference, Lidingo, Sweden; 8-12 Sept. 1985. pp. 13-26. 1986

The core of the idea is that the state of the topological neighbors (in not necessarily Euclidean space) **influences, but not predetermines** the state of a node of a network.

The graph of the network is a subgraph of a full graph on all nodes (as any graph is). This is why I arrange the nodes of the network in a circle: each element can potentially connect with any other. A non-mathematician, I intuitively anticipate a specific kind of semi-regularity in the graphs which I draw here. They are not exactly point lattices, but the limits on the **valency** (degree) of vertices (**arity** of generators in Pattern Theory) prevent combinatorial explosions. This is the essence of thinking: stay focused. I would say, vaguely, that exsystems are severely restricted subsets of the scale of sets.

Unlike the models of interactions on lattices, Eigen's original chemical model does not come to equilibrium. It is driven by non-stop replication, which in chemistry requires thermodynamic openness. At the same time it is cruelly conservative: the number of atoms is constant, although this can be modified.

Eigen's initial model of chemical evolution does not contain a single chemical symbol and remains, I believe, an excellent example of what I call pattern chemistry. The **concentrations**, used in chemical equations, are nothing but probabilities to find a species in a unit volume.

The only computational unit of PROTO—**selection**—calculates the probability distribution at time $t+1$ as:

$$p_i^{t+1} = (p_i^t + \sum_{i,j} G_{i,j} p_j - F p_i^t) ,$$

where F defines forgetting or dissipation and $\sum_{i,j} G_{i,j} p_j$ is a sum of influences on cell i over all neighbors j in the network. Parameter G can be different for different i , j .

There are additional rules interpretable as “the ping-pong player cannot send two balls in a row, but only in turn with the opponent.”

1. The acton A_t selected at time t cannot be selected in time $t+1$.
2. The acton A_t selected at time t “remembers” its probability at time $t+2$ as C , although it cannot be selected again until time $t+2$.
3. At time $t+1$, the neighbors perceive the probability of acton A_t as $H \cdot C$.

All constants, F , C , G , and H , $= < 1$, although it is not necessary. In principle, instead of p_i^t , I could (and even should, following Eigen) use $A p_i^t$, $A > 1$, to reflect

replication, but neural realism forbids it. I believe that parameter **C** sufficiently accounts for a quasi-replication because it increases the subsequent probability of selection. This aspect of thinking needs a separate discussion. See CONCLUSION for some specifics.

Further in the process of selection, the calculated distribution is normalized, probability of previous acton and empty word '!' nullified, and a random number cast for selection. The nullification of '!' is also optional because the empty word may represent a sudden loss of the train of thought for whatever reason.

The remarkably simple premises of SCALE and PROTO open a passage to an extraordinary complexity of choices and possibilities to make the model realistic.

A digression on neural realism follows.

NEURAL REALISM

The term itself has been used, obviously, in the area of simulated neural activity and cognitive models. Regarding PROTO, there are at least two considerations in the gray area of neural realism.

1. Neurons do not grow in numbers the same way organisms, molecules, and money do. Brain is a conservative system regarding matter. However intensely somebody is thinking, we cannot see any brain coming from his ears and we see, actually, nothing growing or even changing in any sense. The activity, of course, is detectable with proper equipment, but are we sure that we see thinking? We actually see metabolism, which is not growth, but dissipation.

The brain uses energy to maintain the neurophysiological activity, which is neither a two-way exchange, as in economy, nor a physical collision as in molecular chemistry, nor a physical multiplication, as in replication of organisms and nucleic acids. Neural events are impulses sent to neighbors in a network. Therefore, Eigen's equations could not be applied either in their initial form, or in their deep replicative meaning. What remains from the idea is **competition for a limited resource**, common for molecules, money, and organisms, as well as for all brain cells (I mean energy) and even their brain owners (I mean "fortune").

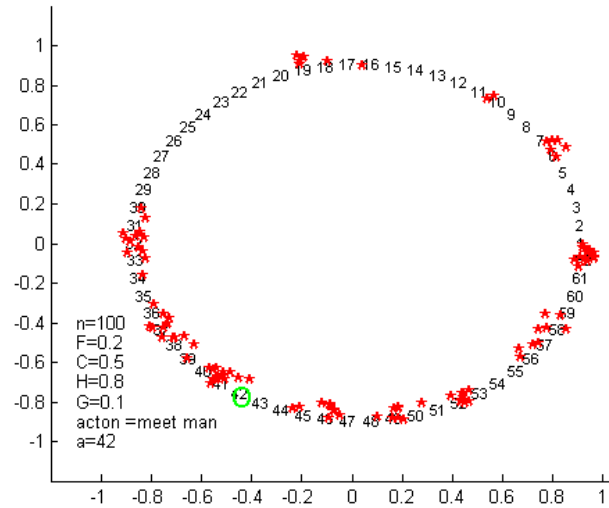
The event in PROTO is the one-time "contest" which results in a winner. As with humans, the participants can try their luck again and again. I do not mean that the competition in the mind is global and it elects a single winner. It happens, probably, all over the mind in a fractal manner.

2. Selected actons cannot retain their status at the next selection. The presence of refractory phase (inactivity after firing) in neuronal activity is the main source of realism in this regard. I can only guess, speculatively, that this cardinal, biologically unavoidable fact of natural neuronal behavior was a **condition for**

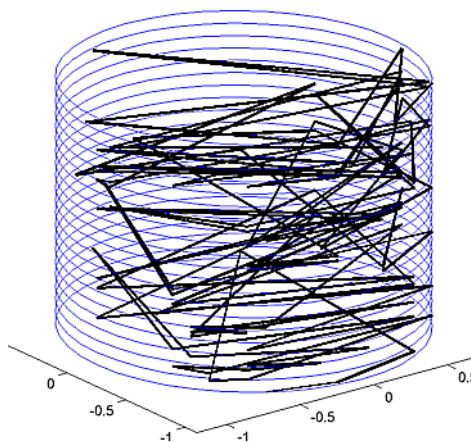
the development of the mind, and not in any sense a limitation. This condition makes neural **dialogue** possible. Marvin Minsky's "Society of Mind" is more than an apt metaphor.

```
AA=[ 46 52 10 39 41 56 39 37
41 45 41 48 38 19 37 52 41 56
32 6 38 52 38 41 38 42 62 36
52 6 32 52 37 62 32 62 37 18
37 56 49 62 49 10 19 62 19 62
41 46 41 46 16 6 57 45 62 6
41 62 42 49 32 49 41 33 41 52
6 52 61 30 6 33 32 33 58 62
49 58 37 52 41 46 62 46 32 47
62 33 49 34 58 19 58 31 46 62
50 56];
```

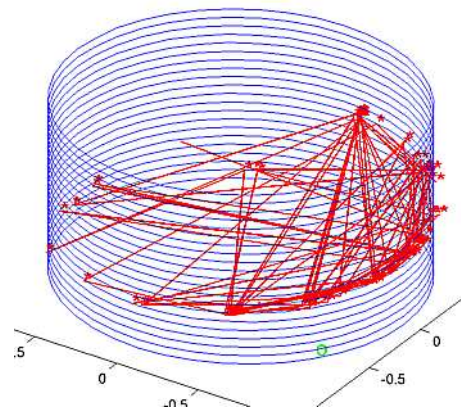
A. Trajectory as a sequence of actons



B. Distribution of actons over NAMES



C. 3D trajectory. Z=1:100



D. Connector of thought. Z=1:62

Figure 9. Trajectory AA and its graphic outputs; $n=100$, $F=0.2$, $C=0.5$, $H=0.8$, $G=0.1$, initial acton $a=42$, 'meet man'

The output of “thinking” is the trajectory: a sequence of the actons which are elevated to star status. To say “consciousness” would be inappropriate here; let us say instead, “borderline area”.

Figure 9 shows the graphic outputs of 100 cycles of “thinking” (i.e., selection of 100 actons) after the initial acton is enforced as doublet 42, ‘**meet man**’. In **Figure 9B** the position of the asterisk which represents an acton is slightly randomized.

Script **nums** (from “numbers”) generates the activated thoughts along with their occurrences (column 2, bold font) and the Jini coefficient of the distribution of occurrences at the end:

>> nums	48 1 give straw	33 4 second pig	52 8 first build
	50 1 straw build	38 4 sent away	41 11 first meet
16 1 bundle	57 1 ask enter	56 4 ask first	62 12 eat first
18 1 say	61 1 wolf eat	58 4 say no	
30 1 sow pig	10 2 sent	6 6 first	total 28
31 1 pig three	39 2 sent seek	32 6 first pig	JINI = 0.596
34 1 third pig	42 2 meet man	37 6 sent first	
36 1 sow sent	45 2 first say	46 6 say man	
47 1 man give	19 4 give	49 6 give first	

Thus, **say** (18) and **sow pig** (30) activate once each, while **first meet** (41) and **eat first** (62) appear 11 and 12 times within the 100 acton sequence. I am tempted to say that “consciousness” has depth and **first meet** and **eat first** are close to the surface, while **bundle** to **first say** sit at the bottom. Actually, I am quite serious. Earlier I proposed to consider consciousness as a cognitive mechanism necessary for linearization: one link of the chain of events at a time. To put it differently, consciousness is a window into the world, narrow enough to see the forest as a set of trees. Consciousness is a condition of cognitive analysis of the world and the synthesis in the form of thinking.

The output of script **nums** is similar to **content** in Ulf Grenander’s GOLEM, while matrix **WW** corresponds to its **connector**. It is a small bowl of thought soup, in which we see pasta pieces of different length and quantity.

6. SPEAKING

At the stage of SPEAKING we already have the right to judge whether the output makes any human sense. We cannot hear the shrieks of thoughts being stretched on the Procrustean bed, but speech escapes the dark dungeons of the mind.

Script **say_con** ("say content"; later changed for **saycon2**) generates all possible triplets from doublets along the Velcro rule of haplology. The program compiles a **content condensate**: list of doublets and triplets of Late Nean, which is a transitional state to full language. The condensate is rather focused, which is expected, but still surprising. It has a potential to be even more condensed, as I will further illustrate, thereby producing longer thoughts and opening a way to full human language, breaking through a crucial transition state.

Here is an example of a trajectory, its content (third column shows number of occurrences), and its condensate:

Trajectory:

```
AA = [46 52 10 39 41 56 39 37 41 45 41 48 38 19 37 52 41 56 32 6 38 52
38 41 38 42 62 36 52 6 32 52 37 62 32 62 37 18 37 56 49 62 49 10 19 62
19 62 41 46 41 46 16 6 57 45 62 6 41 62 42 49 32 49 41 33 41 52 6 52 61
30 6 33 32 33 58 62 49 58 37 52 41 46 62 46 32 47 62 33 49 34 58 19 58
31 46 62 50 56];
```

Content:

	50 1	straw build	56 4	ask first
	57 1	ask enter	58 4	say no
16 1	61 1	wolf eat	6 6	first
18 1	10 2	sent	32 6	first pig
30 1	39 2	sent seek	37 6	sent first
31 1	42 2	meet man	46 6	say man
34 1	45 2	first say	49 6	give first
36 1	19 4	give	52 8	first build
47 1	33 4	second pig	41 11	first meet
48 1	38 4	sent away	62 12	eat first

Content condensate:	give_first_meet ;	sent_first_pig ;
	give_first_pig ;	sent_first_say ;
	give_first_say ;	sow_pig_three ;
eat_first_build ;	give_straw_build ;	sow_sent_away ;
eat_first_meet ;	man_give_ ;	sow_sent_first ;
eat_first_pig ;	man_give_first ;	sow_sent_seek ;
eat_first_say ;	man_give_straw ;	third_pig_three ;
first_meet_man ;	meet_man_give ;	wolf_eat_first ;
first_say_man ;	say_man_give ;	
first_say_no ;	sent_first_build ;	
give_first_build ;	sent_first_meet ;	

Longer regular strings can be velcroed together from the content:

first say man give first pig

Isn't it "First say[s] to man [:] give [something to] first [who is a] pig? " (Just a question).

first meet man give first pig

Isn't it "First meet[s] man [who] give[s something to] first [who is a] pig?" (Just a question!)

A longer and bolder derivation:

first_say_man ; say_man_give ; man_give_straw ; give_straw_build ; →

First say, "Man, give [me some] straw [to] build [a house]."

And don't you see that there were three pigs in a family: **first** [was one] **pig** [out of] **three** ; **second** [was one] **pig** [out of] **three** ; **third** [was one] **pig** [out of] **three** ? Still, the question needs an answer. In the context of the pig story told in Nean, the answer is:

Our interpretation is correct if it does not lead to instability with fellow cavemen.

This is crucial for understanding the emergence of language, but again, it is a separate topic. I believe, the book by Nikolaus Ritt, *Selfish sounds and linguistic evolution. A Darwinian approach to language change* (Cambridge University Press, 2004), should tackle this subject, but I have not yet read it.

Remember that the whole trajectory of THINKING in the last example was triggered by initial acton '**meet man**'. Our baby mind seems to stay focused on the topic. The tragic end of the hero is not forgotten, however: **wolf_eat_first** .

But what is the meaning of the common element in the non-linear clusters with the same beginning or end?

first _meet_man ;	meet_man_ give ;	eat_ first_pig ;
first _pig_three ;	say_man_ give ;	sent_ first_pig ;
first _say_ ;		give_ first_pig ;

For the answer I have to refer to my e-publications on extraction of grammar by simplistic rules: **Salt** and **Salt2**.

The short answer is: common elements in the same position define a **category of grammar**: **first** for subject, **give** for verb, and **first pig** for object.

As soon as the words are categorized, the emerging grammar attributes either order or inflections, or both to them. Thus, **first** is a generalized symbol for all things which can **meet**, **be**, and **say**; **give** is something that at least **man** (and others, as will be seen with more experience) does; **first_pig** symbolizes everything that can be **eaten**, **sent**, and **given** to.

The second interpretation opens a way to **vertical** linearization by common beginning:

man_give_first ;
 → **man give first straw** or **man give straw [to] first**
man_give_straw ;

Indeed, haplology is just a particular case of **contraction**.

sow_sent_away ;
sow_sent_first ; → **sow sent first [pig] away [to] seek [fortune]**
sow_sent_seek ;

There is also a third interpretation: the topic, as in Japanese and some atypical cases of English and other languages.

The modern language begins.

Leaving the cozy simplicity of Nean, humans face a great uncertainty of the choice of grammar. Would that be too hubristic to explain the overwhelming diversity of human languages by their common origin from the extreme simplicity of Nean? By starting from a point on a plane, you can move in any direction, but you have a tree of more narrow choices after the first step. Biological diversity illustrates the principle of “more complexity—less choice” best of all. A leopard can change its spots, but cannot get rid of its vertebrae. In the spirit of pattern chemistry, this applies to any evolution, from life (single cell) to politics (ambition) to Internet (fun of function) to terrorism (fun of killing).

Formally, human speech is just a particular kind of performance, whether improvised or memorized, but usually both. Regarding memory—not less mysterious problem than origin of the universe—here is a digression on the subject.

MEMORY AND LINEARIZATION

Professionals in any area are capable of keeping in memory sequences of words, numbers, movements, and other apparently non-linear configurations as large as a symphony, part in a long play, big chemical formula, epic poem, long mathematical proof, history of a nation, assembly of a device, etc. I suspect that this is possible because of a fast assembly of linear fragmentary thoughts with a hierarchy of Velcro fasteners to put them out as speech or action. It is also possible that long time memory is characterized by an especially conservative set of parameters in Eigen-type equations.

This is where Noam Chomsky's universal grammar comes to mind. If there is anything that could be qualified as universal grammar, it is the inborn ability of fast assembly of a linear behavioral configuration from short linear fragments of thought. The language instinct is to linearize the content of the mind.

There is no originality, especially, after the work of Eric Kandel, in saying that the elementary unit in pattern chemistry of memory is simply a **bond** between two physiological carriers, neurons or not. There is a subtler aspect of the problem, however.

A movie production is a good, albeit too literal, metaphor of assembly of a long sequence from short fragments shot along the linear script in often broken and non-linear order, so that death could be filmed before birth and divorce before marriage.

The performance of an actor on stage is unrolling in the natural time and strictly linear order, it cannot be cut into confetti, as a mortal combat in a violent movie. It appears non-linear, however: the actor (1) speaks and accompanies words with (2) emphatic intonation, (3) gestures, (4) body part movements, (5) facial expressions, (6) silent action, (7) manipulations of objects and partners. At a closer look, however, this complex multidimensional sequence of configurations is a **bundle of parallel linear actions**, which I have just enumerated. It is kept in order by the script.

A symphony is a similar, although more transparent, **fiber bundle**, visualized in the score. Each musician, in turn, performs a mini-symphony of smaller linear parts played by fingers, arms, and lungs. All individual strands of actions are organized by rhythm.

I use this digression to emphasize the contrast between the current paradigm of artificial Artificial Intelligence and its possible alternative, natural Artificial Intelligence. Natural thinking and behavior emerges neither from a likeness of a

computer code, nor from the equations of chaos theory, but from random but organized pattern-chemical interactions and transformations, each with its energy cost. Yet computer (non-parallel), like human mind, linearizes the non-linear **ifs** and **loops** of the code. In this sense, computer speaks without thinking. So, don't be fooled.

7. FROM SPEECH TO UNDERSTANDING

SPEAKING is not supposed to fall on deaf ears. Although SPEAKING of EVE sounds as a crude pidgin English, it is addressed to us, listeners who know the context of the story and probably even have seen a pig and a wolf live. Therefore, we are free to evaluate SPEAKING without the guilt of excessive anthropomorphism. This time we start a new turn of the spiral started by the cave stories as listeners.

We UNDERSTAND speech because it is ordered by the way it is generated by the speaker and is passing through the relatively wide and fading toward the periphery spotlight of consciousness **in the same order**.



The old paper tape telegraph is an appropriate ideogram of verbal communication. What it lacks is the “burn after reading” procedure performed by the ephemeral sound of speech on itself. This cardinal difference between reading and hearing was the point of divergence between spoken and written languages.

In this section I will present some observations of a listener on the behavior of EVE. I am trying to understand what EVE is saying and how it can help understand the origin of thought and language.

By no means I consider EVE a linguistic computer model, whatever I say—for lack of better terms or for excess of enthusiasm—about it here. EVE is just a means to generate **illustrations** of the principles of evolutionary simplicity, which might well apply to any other evolution toward a high complexity, for example, DNA, organism, society, or science. Therefore, the words “behavior of EVE,” which I will use, mean literally the output of some software designed to produce illustrations.

The reason why I want some difficult to achieve clarity in this regard is my skepticism concerning computer models of exsystems. I will return to this point in CONCLUSION.

By protolanguage we may mean at least two hypothetical things. One is the very first spoken language, *die Ursprache*, with its lexicon, and the other is the structure of the first language, regardless of the lexicon and phonology, which is what I mean. It is difficult to achieve consensus on something as hypothetical. Whether Nean is a protolanguage or not a language at all is a matter of definition, which I will put aside.

Thought is not as hypothetical as protolanguage, but it is even more evasive. There is something going on in the mind, which we call “thought” (inner thought, process) but never **see** anything but some brain imaging shadows. There is also thought as the meaning of speech or written sentence (outer thought, content, idea), which can be etched in stone, but from Shakespeare to Sartre to Sarah Palin, to achieve consensus on what

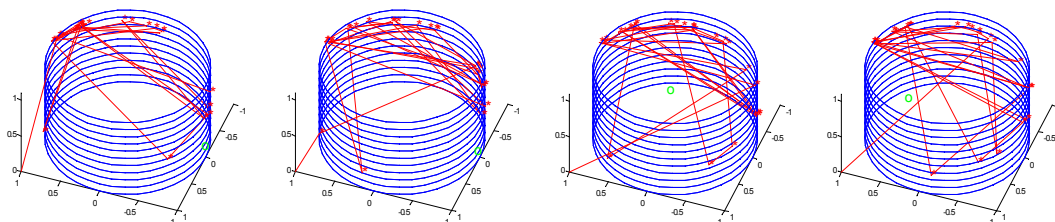
they were thinking before uttering a phrase is not always an easy task. Besides, as [Chisholm's Second Corollary](#) [to Murphy's law] says, "If you explain so clearly that nobody can misunderstand, somebody will."

As a pattern chemist, I see the **inner thought** as a "soup" of fragments and the **outer thought** as their spoken linearization **as it is understood** and can be translated and explained. Instead of "soup" a chemist would say: liquid mixture of short elementary thoughts and longer clusters in motion, i.e., physical suspension or solution (strangely cerebral opposites). "Soup," however, is a standard term in any discussion of chemical origin of life. It is a typical ideogram.

The linear topology, however, is not enough for understanding: thought has to carry a message (thought, message, idea, content—so confusing!). Moreover, thought can carry a message relevant only in a context of a particular situation (a saber-tooth behind partner's back or a philosophy class) or a timeless message retold through generations, like a myth, ancestral lineage, or a real story about the hunter and his partner still remembered by older members of the tribe only because it was **extraordinary**. Message requires tags, like time and place, which asks for a larger and consistent thought, or, rather, a story. Language develops from signal to story.

The behavior of EVE shows some distinct patterns, depending on the parameters **C**, **G**, **H**, and **F**. Regarding selection, the calculation unit (script select3.m) takes to account the arity **Ar** of the NAME) by dividing the sum of influences from the neighbors by $\sqrt{Ar}$. Probably, $\ln Ar$ instead of $\sqrt{Ar}$ should also be tested. This kind of choice is intuitive and I cannot yet find any rationale for it. Random mutations of the algorithm would be the best.

Several types of graphic output are shown next. The runs begin with initiation (equalization of probability distribution), initial acton NAME 53 (**wolf come**), and 150 subsequent cycles in batches of 25, of which only the 25 last are shown here as trajectories in WORLD space, ordered along axis Z from 1 to 62. The actons can flock together either in the last section of the WORLD (upper part of the cylinder) where **wolf** appears (**Figures 10-1 and 10-9**, or, in addition, heavily refer to the 1:28 section of single NAMES (**Figures 10-8 and 10-10**), or are highly condensed, as in **Figures 10-7, and 10-8**.



1: C = 0.5; G = 1; H = 0.8; F = 0.8; **2:** C = 0.5; G = 1; H = 0.8; F = 0.2; **3:** C = 0.5; G = 1; H = 0.2; F = 0.2; **4:** C = 0.2; G = 1; H = 0.2; F = 0.2;

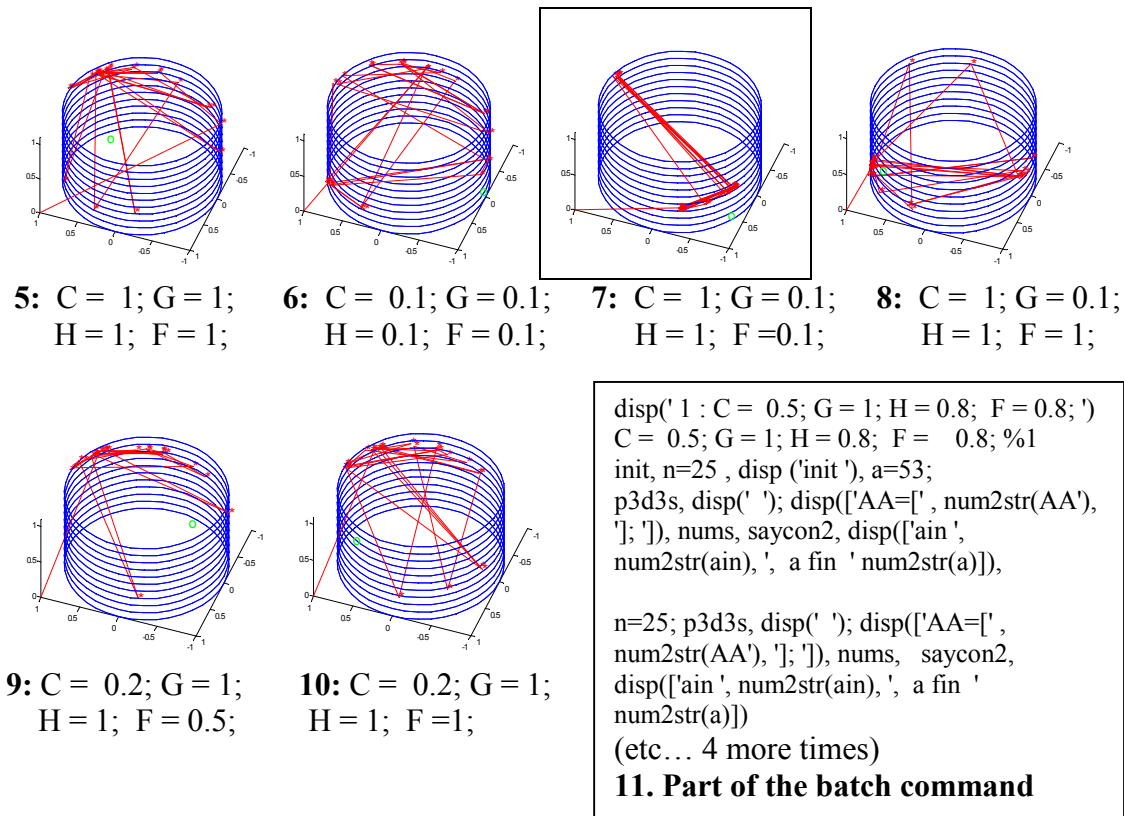


Figure 10. Graphic output of EVE, initial acton “wolf come,” No. 53.

The following is part of text output, $C = 0.5; G = 1; H = 0.8; F = 0.2;$, cycles 75:100.

AA=[54 50 49 48 37 50	10 37 2 sent first	eat_first_say ;
21 32 56 49 56 45 62 49	11 50 2 straw build	first_say_man ; *
62 56 62 61 57 28 37 55	12 54 2 come house	give_straw_build ; *
46 54 62];	13 49 3 give first	wolf_ask_first ; *
content:	14 56 3 ask first	wolf_ask_enter ; *
	15 62 4 eat first	wolf_eat_first ; *
1 21 1 build	condensate:	total content 15
2 28 1 eat	sent_first_pig ; *	condensate 13
3 32 1 first pig	give_first_pig ;	narr. cond.7
4 45 1 first say	ask_first_pig ;	JINI = 0.79
5 46 1 say man	eat_first_pig ;	cond/content = 0.87
6 48 1 give straw	sent_first_say ;	nr.cnd/cnt = 0.47
7 55 1 wolf ask	give_first_say ; *	ain 48, a fin 62
8 57 1 ask enter	ask_first_say ;	
9 61 1 wolf eat		

-----.

The end comments in the output show the sizes of content, condensate, and narrow condensate, Jini inequality coefficient, and the size ratios of condensate and narrow condensate to content.

Asterisks mark triplets, the starting doublets of which, for example, **sent_first + first_pig** → **sent_first_pig**, have the difference of coordinates in WORLD equal to not more than **5**. This difference (**condensate range**) can be varied. I remind that WORLD approximately preserves the order of LISTENING, i.e., **the order of events in the story** (Leibniz: time is order of a sequence of events).

The consistency of the **narrow condensate**, as I call it, improves, as expected, although without much room for further stitching. Thus, the confusing “eat_first_say” and “ask_first_say” do not get into the “thought soup” :

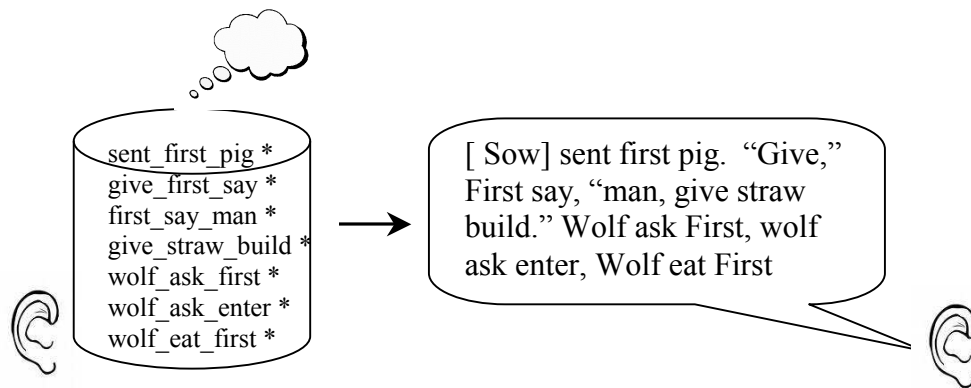


Figure 11. Transmission of thought from condensed thought soup to SPEAKING to LISTENING and toward UNDERSTANDING

A fragment of the story is approximately retold, with gaps.

Let us take the case presented in **Figure 10-7**, $C = 1$, $G = 0.1$, $H = 1$, $F = 0.1$, cycles 126:150. It is marked by a border. With influence of neighbors as low as $G=0.1$ we would expect a very rambling THINKING. Yet with low forgetting F and high C it looks well focused:

content:	5 60 1 blow house	condensate:
	6 57 2 ask enter	eat_first_say ;
1 18 1 say	7 61 3 wolf eat	wolf_ask_enter ; *
2 24 1 ask	8 62 3 eat first	wolf_blow_house ; *
3 45 1 first say	9 22 5 wolf	wolf_eat_first ; *
4 55 1 wolf ask	10 59 7 wolf blow	

Wolf ask enter, wolf blow house, wolf eat first. This is the essence of what happens after **wolf come**.

It might be of interest how content in this particular and strange (**Figure 10-7**) case progresses with time (1:150) from empty condensate. It tells something about the **kinetics**, as the chemists say, of the process: the relatively slow speed which is typical of

most transformations in organic chemistry. A slow chemical kinetics was considered an evidence of a bottleneck and a major stimulus for the theory of transition state.

1:25 content:

1 21 1 build
2 31 4 pig three
3 59 4 wolf blow
4 61 7 wolf eat
5 22 9 wolf

condensate:

[empty]

26:50 content:

1 27 1 blow
2 23 2 come
3 55 2 wolf ask
4 57 3 ask enter
5 59 3 wolf blow
6 53 5 wolf come
7 22 9 wolf

condensate:

wolf_ask_enter ; *

51:75 content:

1 20 2 house
2 53 2 wolf come
3 55 2 wolf ask
4 60 2 blow house

5 22 3 wolf

6 27 4 blow

7 61 4 wolf eat

8 59 6 wolf blow

condensate:

wolf_blow_house ; *

76:100 content:

1 22 1 wolf
2 51 1 build house
3 53 1 wolf come
4 60 2 blow house
5 27 8 blow
6 59 12 wolf blow

condensate:

wolf_blow_house ; *

101:125 content:

1 27 1 blow
2 55 1 wolf ask
3 60 1 blow house
4 20 2 house
5 23 2 come
6 53 2 wolf come
7 61 2 wolf eat

8 22 3 wolf

9 54 4 come house

10 59 7 wolf blow

condensate:

wolf_come_house ; *

wolf_blow_house ; *

126:150 content:

1 18 1 say
2 24 1 ask
3 45 1 first say
4 55 1 wolf ask
5 60 1 blow house
6 57 2 ask enter
7 61 3 wolf eat
8 62 3 eat first
9 22 5 wolf
10 59 7 wolf blow

condensate:

eat_first_say ;

wolf_ask_enter ; *

wolf_blow_house ; *

wolf_eat_first ; *

Thinking could be a slow, truly chemical process, but the result can come any time, which is an evidence that human thinking is a random process in a system of a moderate size. The smaller the system, the sooner the result (i.e., **arrival to stability**). This is why the standard way of solving a difficult problem is to simplify it and to think for a long time, I am not sure in which order. Henri Poincaré and Jacques Hadamard left classical descriptions of the process of mathematical creation, which illustrate the major kinetic properties of thinking .

MEYER'S LAW : "It is a simple task to make things complex, but a complex task to make them simple." One of the reasons why democracy can be as dysfunctional as currently in the USA, is either impossibility of simplification or fast pace of uncontrollable events, or both (see APPENDIX 2). Problem solving could be one of future tasks for EVE and it may turn unsolvable.

The right choice of parameters C, G, H, and F or **just a longer thinking** can probably improve SPEAKING.

The left column in **Table 2** shows the combined **narrow condensate** from **150** cycles at C = 1, G = 1, H = 1, F = 1; the last 25 cycles are shown in **Figure 10-5**. Other columns are some of possible longer derivations. I assume that evolutionary contraction comprises elimination of repeating doublets, as well as singlets, and works vertically, as well as

horizontally, albeit with the inevitable uncertainty of linearization. Note that wrong thoughts are easily generated, too. Animals and humans make mistakes and what can be more natural than an error or an excessive enthusiasm which is often its precursor?

Wolf is not an object of any action and this is why there is no bond to it until the end of the full tripartite story, not yet told. **Meet_man_give** seems clever, but less straightforward: indeed, the distance between **meet_man** and **man_give** in **WORLD** is exactly 5, the maximum.

Table 2. Derivation of longer thoughts from narrow condensate

Narrow condensate	Horizontal derivations	Vertical derivations
ask_first_build; first_build_house; first_meet_man; first_say_man; give_first_build; give_first_say; man_give_first; man_give_straw; meet_man_give; say_man_bundle; say_man_give; sent_first_meet; sent_first_pig; sow_sent_first; sow_sent_seek; wolf_ask_enter; wolf_ask_first ; wolf_blow_house; wolf_eat_first;	ask_first_build_house first_meet_man_give_first, first_say_man_give_straw, first_meet_man_give_straw give_first_say_man_bundle first_meet_man_give_first_build_house first_meet_man_give_straw sow_sent_first_meet_man (dubious) wolf_ask_first_build_house (wrong!)	first: meet man, say man, build house man give: first, straw say man: give, bundle sow sent: first, seek wolf ask: first, enter wolf: blow house, eat first

The vertical contraction of

first_meet_man_give_first_build_house and
first_meet_man_give_straw

gives:

first_meet_man_give_straw_first_build_house .

At this point, the most significant and remarkable result for me is not the possibility of generating long speech-ready thoughts from doublets, but the fact that **doublets alone are sufficient** for verbal communication. Nean seems like a real language of thought. Nevertheless, looking at **Table 2** I have a feeling of a glass wall separating me from the full-blown language.



EVE is just dying for a grammar which would smoothly, without a bottleneck, handle:

man_give_first + man_give_straw → man give first straw OR man give straw first

EVE's behavior definitely gives (at least to myself) some food for thought and generates questions which are halfway to understanding.

Doublets **first_say** (45) and **say_no** (58) are adjacent in the last part of the story, but **first_say_no** is not in the **narrow** content because **first_say** occurs twice, but has only one, much earlier coordinate (45), when **first** talks to **man**. I let it be so out of curiosity, not knowing what to expect, and here is the answer.

The impossibility to have **first_say_no*** in the narrow condensate poses a paradoxical problem: how to resolve this shortcoming without using my own creativity.

A possible way is to somehow use the **natural** signals of the end of phrase, like pause, intonation, or a word in a fixed syntactic position at the end of phrase, as, for example, the Japanese verb. Russian colloquial “nu” and its English counterpart “well” in the beginning of a spoken phrase convey the start of a thought expression. I believe the sterility will be preserved if we simply consider them (and punctuation marks) NAMES, but this seems already far beyond Nean. An intriguing question: when I think about fixing a problem in EVE, do I follow the same pattern as the evolving natural language did? Yes, but not as a blind watchmaker. *Nu*, well, how can I be sure?



It has taken me some time to notice that **first_say** is the only doublet that has been classified by SCALE as old during LISTENING. Therefore, something must happen with it on the second occurrence which does not happen with the rest of NAMES. What “second occurrence” implies is the single continuous timeline (history) of the system, which is the intrinsic property of an exsystem and part of its definition. At normal conditions no memory of an exsystem can be externally manipulated, even if it is an Orwellian exsystem.

While I am developing some ideas about improving EVE, I realize that they are not sterile. I do not have a clear vision how the natural EVE could arrive to any such step on its own. But am I really outside EVE if it is a creation of my mind? I know introspectively that my thinking is not algorithmic and, therefore (can we even say “therefore?”), as chaotic as the movements of a trapped animal. I assume that in a way it is a recapitulation of some stages of phylogenesis of the mind. EVE stimulates asking difficult and troubled questions. The deepest among them is how the phylogenesis of mind can be spontaneously recorded, i.e., what is the genome of the mind? In molecular chemistry and AI this question is easy to answer.

There is another—smaller—problem: what to do about erroneous outer thoughts like **wolf_ask_first + ask_first_build + first_build_house → wolf ask first build house?** Is it enough to say that to err is human? It could be, of course, an honest mistake of a child retelling the story or answering a question. Now we are talking about possible psychological, not digital, experiments, but I intend to stay with pattern chemistry which is trans-disciplinary.

Evolution **is a sequence of solved problems**: a steeplechase of successfully passed **transition barriers**, speaking chemically, known as **punctuated equilibrium** in biology.

I suggest the sterility condition for evolutionary games as:

The solution must be so simple that it could occur at random,

like the variation of the parameters and the size of the spotlight at SPEAKING. I must confess, however, that I had invented the variable spotlight myself (it suddenly occurred to me after intense chaotic, soup-like thinking) and found the excuse later. I hope this illustrates what I mean by intellectual infection and how difficult it is to avoid it in Natural Artificial Intelligence.

The above results illustrate, in my opinion, the importance of the knowledge acquisition through stories, procedures, and, generally, sequences, which opens, thorough the evolutionary feedback, a way to complex knowledge. This is why children should be told consistent stories. Origin of language is inseparable from the actual living conditions, environment, and material culture. Its closest pattern-chemical parallel is the origin of the cell genome. To fantasize further, the consciousness, which is the cauldron for the momentary batch of the thought soup, should not be either too big, or too small. Moreover, there could be various levels of **wider** subconsciousness below the narrow working consciousness.

In big systems some combinatorial situations can never realize, while in small systems they constantly repeat but do not have much choice.

A speculative discussion of all these problems could be endless. This is a good time to stop SPEAKING and do more THINKING.

8. CONCLUSION

No firm conclusion can be made from the first preliminary computer games.

But what exactly does “firm conclusion” mean?

The value of computer simulations is a vast and controversial topic. Manfred Eigen’s entire work in chemical evolution could be questioned in this regard, not to mention the whole boundless area of the hectic activity of modern descendants of mythical centaurs: humans fused with controlled computer and computers fused with controlled humans.

I tend to draw a sharp distinction between **realistic** models, like weather, bridge, and airplane, and **speculative** modeling, like ALIFE (Artificial Life) and econophysics. Ulf Grenander’s GOLEM belongs to the second category. On the contrary, Pattern Theory of medical image processing belongs to the first type.

The significance of the first kind is that it generates knowledge, while the second kind generates understanding. The whole Pattern Theory is, first of all, a way to understand the complex world as a whole, regardless of what money we can make on that. Knowledge today is for sale, but understanding is still almost free. Have in mind, however, that understanding can be wrong, while knowledge is testable and certifiable.

I start Nean with extreme simplicity, but very soon the horizons of extreme complexity come near, within an arm distance. In order to draw even speculative, but somewhat firmer, conclusions, I have to explore so many combinations of so many factors, that with the means at my disposal it would take a second life. Besides, I believe that for the sake of knowledge the mind should be built, not just simulated. Chemists just go to the bench and do what has to be done, quite like the heroes of John Wayne.

Manfred Eigen was earlier in his life awarded Nobel Prize for fine experimental work on “immeasurably fast” chemical reactions, based on an ingenious theoretical idea. Much later he expressed (see [long interview](#)) the relation between theory and experiment in this way: “No theory without experiment and no experiment without theory.” Obviously, he could not be satisfied with speculation alone and his work after 1980 became experimental. Note, however, that it is not yet about **origin** of life and beginning of evolution, but about replication of biopolymers.

I stop here with a hope to be able to continue. I see the significance of the first speculative “experiments” in making the first **simple** step from **simplicity** to complexity and discovering that it in fact complexity emerges if we repeat simple steps. Whether it

all is true, false, or irrelevant (Manfred Eigen's tree-fold classification), I cannot say. The experiment, ultimately, would consist in **educating** a young EVE until it satisfies the Turing test even at a level much below Commander Data from *Star Trek*. It should be a machine with personality, capable of honest errors and progress.

Why is it important to be natural? Here is an example. The choice of **G** is especially difficult because words differ in the number of connections (arity, **Ar**). I have not yet decided on the choice of **G** and use in **saycon2** a coefficient **B** in **B·G**: $B = 1 / \sqrt{Ar}$. To tinker with parameters, however, is a cumbersome and very AI-ish work. A much more daring step toward naturalization would be to let the model search for maximum stability in the interaction with the human environment, registering the frustration or satisfaction of the humans around the model, as well as the "mood" of EVE. The idea, on which I have a fixation, that homeostasis is in the core of intelligence comes from Ross Ashby.

I must acknowledge that I have been ignoring the growing and exciting area of research on embodied agents and embodied evolution, including evolution of language, to which [Stefano Nolfi](#) has kindly drawn my attention. The word **embodied** here has no esoteric connotation and means simply that the objects of study are material objects and not just manipulation of digits in computers. In my opinion it is the direction which both John Wayne (whose sharp shots were fake) and Ross Ashby (whose rambling homeostat was 100% real) would welcome. Robots consume and dissipate energy, without which no exsystem is possible. They can compete for a limited resource of energy, matter, and space, which is all we want from an avatar (move aside, John Wayne!) of the real life. I am especially interested in the stability dynamics of robots and their societies and whether their behavior is of the Levi walk type. How would they interact with a human? A dog?

It is my uneducated impression that embodied evolution has one important thing in common with classical artificial AI: the "genome" of neural networks, i.e., the feature that can be varied at random and submitted for selection, is explicit, observable, and controllable, quite like the molecular genome. This is a very strong realistic side of it. A big general question is: could that be in principle different for natural AI and, for that matter, natural-natural intelligence? Obviously, the parameters in EVE can be varied at random, but EVE seems less deterministic because random process is the very essence of blind selection. Biological selection is probabilistic and has no goal. Artificial AI selection is done by evaluating the result, like in sports.

This problem has an eerie aura of logical paradoxes and I do not yet have an answer. It might be impossible to get it other than from neurophysiology, but if so, is pattern chemistry of any value? On value is certain: it stimulates questions.

If not a firm conclusion than at least a soft one:

How far can we progress in understanding the origin of thought and language? "How far back can we go ahead," should I say because the question addresses a very distant past. The answer is: as far as a general theory permits. In my **firm** opinion, this general theory cannot be a theory of origin of thought and language, but a theory of any origin of

complex systems, in particular, exsystems. This theory, as any theory of natural process, should have its own kind of generalized physics and chemistry which could tell us what mental constructs are more realistic than others. For two major reasons Pattern Theory (Ulf Grenander) is the only paradigm of this caliber: (1) in its trans-disciplinary approach it considers human thoughts, material objects, and anything between them on an equal basis as combinatorial structures and (2) it distinguishes between more probable and less probable structures and their transformations.

Finally, I want to accentuate that this project comes from Ulf Grenander's "*Patterns of Thought*" and the foundation which he had laid down around 1970, the time of many new and fundamental ideas in science, some still neglected or overwhelmed by faster sellable trends. For more on the mystery of 1970 see [Introduction to Pattern Chemistry](#).

Shouldn't I also mention other predecessors, from Kant and Plato to the first speakers of Nean, in reversed order?

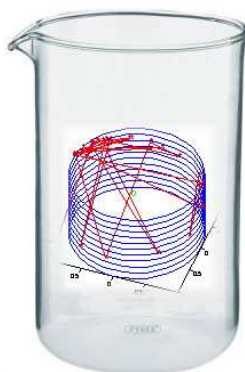
It was Hegel who tried to pull out the big and complex world (in a trans-disciplinary fashion!) from the hat filled **simply** with being (*das Sein*) and nothing (*das Nichts*). Thus, if King Solomon says that there is nothing new under the sun, obviously, the opposite idea must be so reasonable that it needs to be denied. Niels Bohr summarizes: "The opposite of a trivial truth is false; the opposite of a great truth is also true."

MATLAB scripts (amateurish) are published separately and referred to in **APPENDIX 3**, next pages.

[email](#)

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APPENDIX 1. PREVIOUS RELATED E-PUBLICATIONS

(also stored at SCRIBD)

[Molecules and Thoughts: Pattern Complexity and Evolution in Chemical Systems and the Mind](#) (2003) ; [SCRIBD](#)

[TIKKI TIKKI TEMBO and the Chemistry of Protolanguage](#) (2004) ; [SCRIBD](#)

[Pattern Theory and “Poverty of Stimulus” Argument in Linguistics](#) (2004) ; [SCRIBD](#)

[The Three Little Pigs : Chemistry of language acquisition](#) (2005) ; [SCRIBD](#)

[Salt: The Incremental Chemistry of Language Acquisition](#) (2005) ; [SCRIBD](#)

[Salt 2: Incremental Extraction of Grammar by Simplistic Rules](#) (2005) ; [SCRIBD](#)

[The Chemistry of Semantics](#) (2005) ; [SCRIBD](#)

[Do Pirahã speak Nean?](#) (2007) ; [SCRIBD](#)

APPENDIX 2 . SOME QUESTIONS AND ANSWERS

The following questions and answers may help clarify the approach of pattern chemistry.

1. Q: Why do I need to refer to the Great Depression or grumble about the dysfunctional American government in an opus on origin of language?

A: Pattern chemistry, as, more generally, Pattern Theory, is trans-disciplinary. It sees the world through the filter of patterns. Pattern is a space of configurations related through a similarity transformation. Transformation makes sense for not less than two configurations. The more configurations, the more distinct the pattern.

2. Q: In Bourbaki's scale of sets, a combination of elements of a set enters the set as a new element. If this is a general pattern of complexification, what prevents it in nature? It is said usually that brain contains billions of cells and even larger number of their

connections. If so, brain could be as lost in its own complexity as the American political system. Yet even some college dropouts can make swift and clever decisions in complex matters. What limits the connectivity?

A: The actual history of the system. Only one or a few out of many combinatorial possibilities in fact happens. History of an exsystem squeezes out a thin spaghetti from the combinatorial space of connectivity.

3. **Q:** Marco Mirolli and Domenico Parisi ask: [How can we explain the emergence of a language which benefits the hearer but not the speaker?](#) (*Connection Science*, 17(3-4): 307-324). I take the question just as an example, but how would pattern chemistry answer this and similar questions about benefits and fitness?

A: The idea that **beneficial** changes are preserved and evolution is survival of the **fittest** is the key tenet of Darwinism. Yet it has always looked like a tautology. The statement that the world was created in six days does not look circular at all and, although **decently** false, is capable of winning some minds. The paradigm of embodied artificial evolution is more consistent: fitness is defined as performance of a certain function. If something extra happens, it is recorded, and so be it. The very essence of neural network requires somebody or something to approve or reject the state of the network and the distribution of connectivity and weights.

The answer of pattern chemistry is typically chemical: evolution is a search for stability. Since both hearer and speaker are subsystems of the same exsystem, even if they do not cooperate or interact in any way, the property of verbal communication stabilizes the system by adding bonds. There is more finesse, however: if two trends compete, the fastest is more probable to win or dominate. This releases us from the duty to justify haplology, contraction, loss of grammatical gender and case endings, or any other simplification in the evolution of language. If I am not mistaken, Kolmogorov complexity (although I am not a fan of it) is, roughly, the minimal and, therefore, the **fastest** to transmit length of a certain string of symbols. **Faster** and **slower** are the prime terms of chemical kinetics.

APPENDIX 3 : SCRIPTS and WORKSPACE

Any trajectory AA (as a vertical array: AA=[...] ') can be replayed by script **repro** (in WORLD space) or script **tr3d** in time, quite like a video.

**Codes are in separate APPENDIX file , periodically revised,
last revision : February 19, 2010**

scripts and workspace as text file: <http://spiropero.net/eve-scripts.txt>

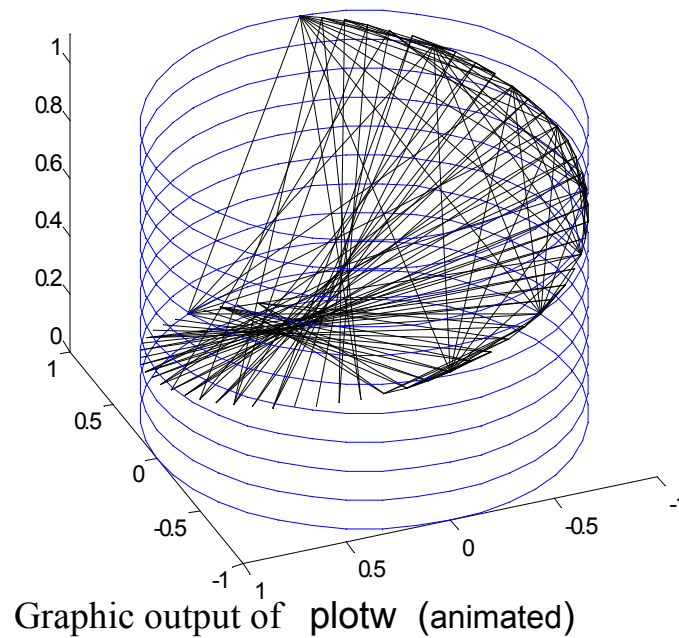
scripts and workspace as pdf <http://spiropero.net/eve-scripts.pdf>

<http://www.scribd.com/doc/26046555/APPENDIX-to-PATTERN-CHEMISTRY-OF-THOUGHT-AND-SPEECH>

LIST OF SCRIPTS:

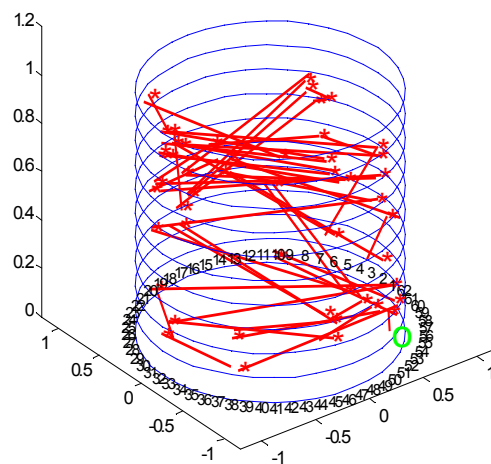
Part 1: SCALE

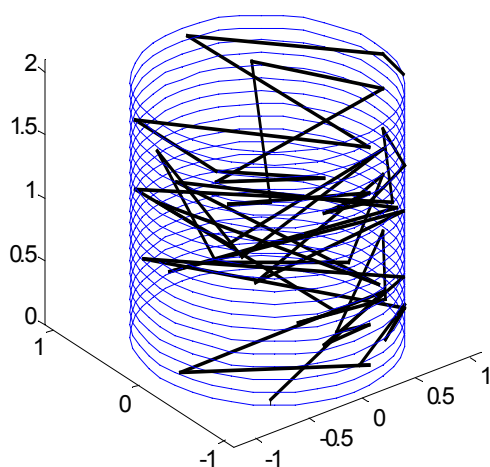
1. SCALE
2. LINK
3. PLOTW



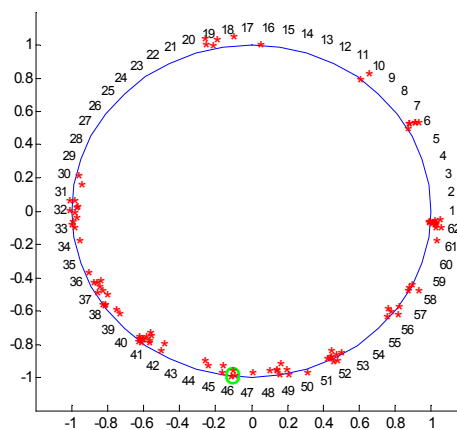
Part 2: EVE

1. INIT
2. P3D3
3. SELECT3
4. NUMS
5. SAYCON2
- 5A. SAY_CON
6. STACK
7. TR
8. TR3D
9. REPRO
(replays AA)
10. REPRO2d
(2D distribution of actons)





**Graphic output of tr3d. Axis
Z is time (animated)**



Graphic output of repro2d

Last updated: November, 2010

APPENDIX to:

Yuri Tarnopolsky

PATTERN CHEMISTRY OF THOUGHT AND SPEECH AND THEIR
HYPOTHETICAL ANCESTOR

main page:

<http://spirospero.net/thought-and-speech.pdf> and
<http://www.scribd.com/doc/26045810/Yuri-Tarnopolsky-PATTERN-CHEMISTRY-OF-THOUGHT-AND-SPEECH>

Check for updates; **last update: November, 2010**

APPENDIX contains workspace and MATLAB scripts

scripts as text file: <http://spirospero.net/eve-scripts.txt>
scripts as pdf <http://spirospero.net/eve-scripts.pdf>
<http://www.scribd.com/doc/26046555/APPENDIX-to-PATTERN-CHEMISTRY-OF-THOUGHT-AND-SPEECH>

CONTENTS

- Part 1 Workspace
- Part 2 SCALE
- Part 3 EVE
- Part 4 Example of a batch command
- Part 5 Structure of WORLD (62x62)

Part 1. WORKSPACE

RECONSTRUCTION OF WORKSPACE FOR EVE

The workspace for **EVE** needs only **WW.mat** (62 x 62) and **NAMES.mat** (62 x 12)

1. RECONSTRUCTING WW

Connectivity list generated from sparse(WW)

```
WWM= [ 29,2 , 30,2 , 35,2 , 36,2 , 29,3 , 30,4 , 31,4 , 32,4 , 33,4 , 34,4 , 31,5 , 32,6 , 37,6 , 41,6 , 45,6 ,  
49,6 , 52,6 , 56,6 , 62,6 , 33,7 , 34,8 , 35,9 , 36,10 , 37,10 , 38,10 , 39,10 , 38,11 , 39,12 , 40,12 , 40,13 ,  
41,14 , 42,14 , 42,15 , 43,15 , 46,15 , 47,15 , 43,16 , 44,16 , 44,17 , 48,17 , 50,17 , 45,18 , 46,18 ,  
58,18 , 47,19 , 48,19 , 49,19 , 51,20 , 54,20 , 60,20 , 50,21 , 51,21 , 52,21 , 53,22 , 55,22 , 59,22 ,  
61,22 , 53,23 , 54,23 , 55,24 , 56,24 , 57,24 , 57,25 , 58,26 , 59,27 , 60,27 , 61,28 , 62,28 , 2,29 ,  
3,29 , 30,29 , 35,29 , 36,29 , 2,30 , 4,30 , 29,30 , 31,30 , 32,30 , 33,30 , 34,30 , 35,30 , 36,30 ,  
4,31 , 5,31 , 30,31 , 32,31 , 33,31 , 34,31 , 4,32 , 6,32 , 30,32 , 31,32 , 33,32 , 34,32 , 37,32 ,  
41,32 , 45,32 , 49,32 , 52,32 , 56,32 , 62,32 , 4,33 , 7,33 , 30,33 , 31,33 , 32,33 , 34,33 , 4,34 ,  
8,34 , 30,34 , 31,34 , 32,34 , 33,34 , 2,35 , 9,35 , 29,35 , 30,35 , 36,35 , 2,36 , 10,36 , 29,36 ,  
30,36 , 35,36 , 37,36 , 38,36 , 39,36 , 6,37 , 10,37 , 32,37 , 36,37 , 38,37 , 39,37 , 41,37 , 45,37 ,  
49,37 , 52,37 , 56,37 , 62,37 , 10,38 , 11,38 , 36,38 , 37,38 , 39,38 , 10,39 , 12,39 , 36,39 , 37,39 ,  
38,39 , 40,39 , 12,40 , 13,40 , 39,40 , 6,41 , 14,41 , 32,41 , 37,41 , 42,41 , 45,41 , 49,41 , 52,41 ,  
56,41 , 62,41 , 14,42 , 15,42 , 41,42 , 43,42 , 46,42 , 47,42 , 15,43 , 16,43 , 42,43 , 44,43 , 46,43 ,  
47,43 , 16,44 , 17,44 , 43,44 , 48,44 , 50,44 , 6,45 , 18,45 , 32,45 , 37,45 , 41,45 , 46,45 , 49,45 ,  
52,45 , 56,45 , 58,45 , 62,45 , 15,46 , 18,46 , 42,46 , 43,46 , 45,46 , 47,46 , 58,46 , 15,47 , 19,47 ,  
42,47 , 43,47 , 46,47 , 48,47 , 49,47 , 17,48 , 19,48 , 44,48 , 47,48 , 49,48 , 50,48 , 6,49 , 19,49 ,  
32,49 , 37,49 , 41,49 , 45,49 , 47,49 , 48,49 , 52,49 , 56,49 , 62,49 , 17,50 , 21,50 , 44,50 , 48,50 ,  
51,50 , 52,50 , 20,51 , 21,51 , 50,51 , 52,51 , 54,51 , 60,51 , 6,52 , 21,52 , 32,52 , 37,52 , 41,52 ,  
45,52 , 49,52 , 50,52 , 51,52 , 56,52 , 62,52 , 22,53 , 23,53 , 54,53 , 55,53 , 59,53 , 61,53 , 20,54 ,  
23,54 , 51,54 , 53,54 , 60,54 , 22,55 , 24,55 , 53,55 , 56,55 , 57,55 , 59,55 , 61,55 , 6,56 , 24,56 ,  
32,56 , 37,56 , 41,56 , 45,56 , 49,56 , 52,56 , 55,56 , 57,56 , 62,56 , 24,57 , 25,57 , 55,57 , 56,57 ,  
18,58 , 26,58 , 45,58 , 46,58 , 22,59 , 27,59 , 53,59 , 55,59 , 60,59 , 61,59 , 20,60 , 27,60 , 51,60 ,  
54,60 , 59,60 , 22,61 , 28,61 , 53,61 , 55,61 , 59,61 , 62,61 , 6,62 , 28,62 , 32,62 , 37,62 , 41,62 ,  
45,62 , 49,62 , 52,62 , 56,62 , 61,62 ];
```

Reconstruction:

1. enter: WWM

2. enter:

```
WW=zeros(62,62); lwwm=length(WWM);  
for j = (1 : 2 : lwwm), wx = WWM(j); wy = WWM(j+1); WW(wx, wy)=1; end
```

Check with the original:

```
>> sparse(WW)
```

ans =

(29,2) 1	(47,19) 1	(4,32) 1	(41,37) 1	(43,44) 1	(62,49) 1
(30,2) 1	(48,19) 1	(6,32) 1	(45,37) 1	(48,44) 1	(17,50) 1
(35,2) 1	(49,19) 1	(30,32) 1	(49,37) 1	(50,44) 1	(21,50) 1
(36,2) 1	(51,20) 1	(31,32) 1	(52,37) 1	(6,45) 1	(44,50) 1
(29,3) 1	(54,20) 1	(33,32) 1	(56,37) 1	(18,45) 1	(48,50) 1
(30,4) 1	(60,20) 1	(34,32) 1	(62,37) 1	(32,45) 1	(51,50) 1
(31,4) 1	(50,21) 1	(37,32) 1	(10,38) 1	(37,45) 1	(52,50) 1
(32,4) 1	(51,21) 1	(41,32) 1	(11,38) 1	(41,45) 1	(20,51) 1
(33,4) 1	(52,21) 1	(45,32) 1	(36,38) 1	(46,45) 1	(21,51) 1
(34,4) 1	(53,22) 1	(49,32) 1	(37,38) 1	(49,45) 1	(50,51) 1
(31,5) 1	(55,22) 1	(52,32) 1	(39,38) 1	(52,45) 1	(52,51) 1
(32,6) 1	(59,22) 1	(56,32) 1	(10,39) 1	(56,45) 1	(54,51) 1
(37,6) 1	(61,22) 1	(62,32) 1	(12,39) 1	(58,45) 1	(60,51) 1
(41,6) 1	(53,23) 1	(4,33) 1	(36,39) 1	(62,45) 1	(6,52) 1
(45,6) 1	(54,23) 1	(7,33) 1	(37,39) 1	(15,46) 1	(21,52) 1
(49,6) 1	(55,24) 1	(30,33) 1	(38,39) 1	(18,46) 1	(32,52) 1
(52,6) 1	(56,24) 1	(31,33) 1	(40,39) 1	(42,46) 1	(37,52) 1
(56,6) 1	(57,24) 1	(32,33) 1	(12,40) 1	(43,46) 1	(41,52) 1
(62,6) 1	(57,25) 1	(34,33) 1	(13,40) 1	(45,46) 1	(45,52) 1
(33,7) 1	(58,26) 1	(4,34) 1	(39,40) 1	(47,46) 1	(49,52) 1
(34,8) 1	(59,27) 1	(8,34) 1	(6,41) 1	(58,46) 1	(50,52) 1
(35,9) 1	(60,27) 1	(30,34) 1	(14,41) 1	(15,47) 1	(51,52) 1
(36,10) 1	(61,28) 1	(31,34) 1	(32,41) 1	(19,47) 1	(56,52) 1
(37,10) 1	(62,28) 1	(32,34) 1	(37,41) 1	(42,47) 1	(62,52) 1
(38,10) 1	(2,29) 1	(33,34) 1	(42,41) 1	(43,47) 1	(22,53) 1
(39,10) 1	(3,29) 1	(2,35) 1	(45,41) 1	(46,47) 1	(23,53) 1
(38,11) 1	(30,29) 1	(9,35) 1	(49,41) 1	(48,47) 1	(54,53) 1
(39,12) 1	(35,29) 1	(29,35) 1	(52,41) 1	(49,47) 1	(55,53) 1
(40,12) 1	(36,29) 1	(30,35) 1	(56,41) 1	(17,48) 1	(59,53) 1
(40,13) 1	(2,30) 1	(36,35) 1	(62,41) 1	(19,48) 1	(61,53) 1
(41,14) 1	(4,30) 1	(2,36) 1	(14,42) 1	(44,48) 1	(20,54) 1
(42,14) 1	(29,30) 1	(10,36) 1	(15,42) 1	(47,48) 1	(23,54) 1
(42,15) 1	(31,30) 1	(29,36) 1	(41,42) 1	(49,48) 1	(51,54) 1
(43,15) 1	(32,30) 1	(30,36) 1	(43,42) 1	(50,48) 1	(53,54) 1
(46,15) 1	(33,30) 1	(35,36) 1	(46,42) 1	(6,49) 1	(60,54) 1
(47,15) 1	(34,30) 1	(37,36) 1	(47,42) 1	(19,49) 1	(22,55) 1
(43,16) 1	(35,30) 1	(38,36) 1	(15,43) 1	(32,49) 1	(24,55) 1
(44,16) 1	(36,30) 1	(39,36) 1	(16,43) 1	(37,49) 1	(53,55) 1
(44,17) 1	(4,31) 1	(6,37) 1	(42,43) 1	(41,49) 1	(56,55) 1
(48,17) 1	(5,31) 1	(10,37) 1	(44,43) 1	(45,49) 1	(57,55) 1
(50,17) 1	(30,31) 1	(32,37) 1	(46,43) 1	(47,49) 1	(59,55) 1
(45,18) 1	(32,31) 1	(36,37) 1	(47,43) 1	(48,49) 1	(61,55) 1
(46,18) 1	(33,31) 1	(38,37) 1	(16,44) 1	(52,49) 1	(6,56) 1
(58,18) 1	(34,31) 1	(39,37) 1	(17,44) 1	(56,49) 1	(24,56) 1

(32,56) 1	(62,56) 1	(46,58) 1	(27,60) 1	(59,61) 1	(49,62) 1
(37,56) 1	(24,57) 1	(22,59) 1	(51,60) 1	(62,61) 1	(52,62) 1
(41,56) 1	(25,57) 1	(27,59) 1	(54,60) 1	(6,62) 1	(56,62) 1
(45,56) 1	(55,57) 1	(53,59) 1	(59,60) 1	(28,62) 1	(61,62) 1
(49,56) 1	(56,57) 1	(55,59) 1	(22,61) 1	(32,62) 1	
(52,56) 1	(18,58) 1	(60,59) 1	(28,61) 1	(37,62) 1	
(55,56) 1	(26,58) 1	(61,59) 1	(53,61) 1	(41,62) 1	
(57,56) 1	(45,58) 1	(20,60) 1	(55,61) 1	(45,62) 1	

2. RECONSTRUCTION OF **NAMES.mat** , size 62x12

```
NAMES=char('!','sow','old','pig','three','first','second','third','poor',
'sent','away','seek','fortune','meet','man','bundle','straw','say',
'give','house','build','wolf','come','ask','enter','no','blow','eat',
'sow old','sow pig','pig three','first pig','second pig','third pig','sow poor',
'sow sent','sent first','sent away','sent seek','seek fortune','first meet','meet
man','man bundle','bundle straw','first say','say man','man give','give straw',
'give first','straw build','build house','first build','wolf come','come house',
'wolf ask','ask first','ask enter','say no','wolf blow','blow house','wolf eat',
'eat first');
```

Part 2: SCALE

1. SCALE

% PROGRAM SCALE, script sc; RELATED: link;

% 1. INITIALIZE

```
S=input('1 to start, 2 to continue ');
nn=input('enter number of cycles (nn): ');
disp(' ATTENTION: Interspaced components should be entered')
disp(' between apostrophes as single string of characters');
disp(' ');
disp(' press any key to continue') ; pause;
```

% 2. START

```
for n=1:nn, if (S==1)&(n==1), sw=1; W=zeros(sw, 16,8);
    NAMES=['!']; WW=zeros(sw,sw);NM=[ ];
    end
```

% 3. INPUT

```
I=input('enter components ');
```

% 4. CONVERT INPUT into PIN;

```
PIN=zeros(8,8); word=[];jj=1; I=[I, ' ']; ab=abs(I); lab=length(ab);  
for i=1:lab, if (ab(i)~=32, word=[word,ab(i)]; else  
lw=length(word); PIN(jj,1:lw)=word; word=[]; jj=jj+1; end, end
```

% 5. CHECKING novelty of PIN against WORLD

```
old=0; wiold=0; comp=[]; % PIN presumed new
```

```
for wi=1:sw %wi: length of World
```

```
% 5.1 CUTTING FLAT SLICE OF WORLD W(wi,,:) )
```

```
fW=zeros(16,8); fW(:,:)=W(wi,,:);
```

% 5.2 COMPARE flat W and PIN as ordered sets %

```
eqid=isequal(fW(9:16,:),PIN); if eqid==1, old=1; %PIN is OLD  
disp('This is old '),disp(NAMES((wi,:)), % wiold=wi; list=find(WW(:,wiold));  
leli=length(list); SN=[];for k=1:leli, SN=strvcat(SN,NAMES((leli,:)));  
end  
end
```

% 5.3 COMPARE flat W and PIN as sets

```
set=0;  
if isempty(setxor(fW((1:8),:),PIN,'rows')),if old==0,  
if eqid~=1,  
note = ['Looks like W' ,int2str(wi),': ', NAMES(wi,:)];  
disp(note); set=1; end, end,old=1; end  
%%%%%%%%%
```

```
if set==1,  
nnew=input(' Is it new? 1/0 ');
```

```
if nnew==1,old=0; end, end
```

% 5.4. CHECK for SET MEMBERS to create SPECTRUM;

```
eqcomp = intersect(PIN,fW , 'rows'); h=size(eqcomp,1) ; test=zeros(1,8);
```

```
for hh=1:h,
```

```
if ((~isempty(eqcomp))&(~isequal(eqcomp(hh,:),test))),
```

```
comp=[comp,wi];end, end
```

```
end %for wi=1:sw
```

```
spectrum=unique(comp);les=length(spectrum);
```

```
%disp('spectrum: '); %for r=1:les, disp(NAMES(spectrum(r,:))); end
```

```
%if old==1,SNU=unique(SN,'rows');disp('OLD spectrum '),disp(SNU),end,
```

% 6. IF NEW, EXPAND THE WORLD:

% 6.1. NAME THE NEW ENTRY

```
if old==0, NAME=input('This is new. Name it ');
```

```
NAMES=strvcat(NAMES, NAME);
```

% 6.2. CREATE NewPIN containing NAME

```

NAME=[NAME, ' ']; NewPIN=zeros(8,8);word=[];jj=1; ab=abs(NAME);
lab=length(ab); for i=1:lab, if (ab(i))~=32, word=[word,ab(i)];else
    lw=length(word); NewPIN(jj,1:lw)=word; word=[];jj=jj+1; end,
end

```

% 6.3.ADD PIN and NewPIN to WORLD

```

sw=sw+1; WW(sw,:)=0; WW(:,sw)=0;% PLACE IN THE WORLD
W(sw,9:16,:)=NewPIN(:,:); W(sw,1:8,:)=PIN(:,:);
% All 16 lines in WORLD are filled up

```

% 6.4. RECORD NEW LINKS

```

for ll=1:les, if ~isempty(spectrum(ll)),
    WW(sw,spectrum(ll))=1; WW(spectrum(ll),sw)=1;end, end,
end
% if old==0,
%To read an entry from W(x,y,:)
%D=nonzeros(W(x,y,:)); D=D'; setstr(D);
end % for n=1:nn
NM=NAMES; world=WW;
disp('If you want to check WORLD for a name, type: link ')
disp('To see NAMES, type: NAMES or NM ');
disp('To display the 3D world, type plotw ');

```

2. LINK

% CHECKING THE WORLD FOR NAME; SCRIPT: link

```

I=input('NAME to check ');
CI=cellstr(I);
SC=nonzeros(strmatch(CI,NAMES));%find NAME's numbers
LINKS=find(WW(:,SC)); links=LINKS';
LL= [ ]; %list of links
NAMELIST=[];
for i=1:length(SC)
    LL= [LL,(find(WW(:,SC(i))))'];
end
lel=length(LL);
for r=1:lel, NAM=(NAMES(LL(r,:))); NAMELIST=strvcat(NAMELIST,NAM);end,
NAMELIST=unique(NAMELIST,'rows'); disp(NAMELIST)

```

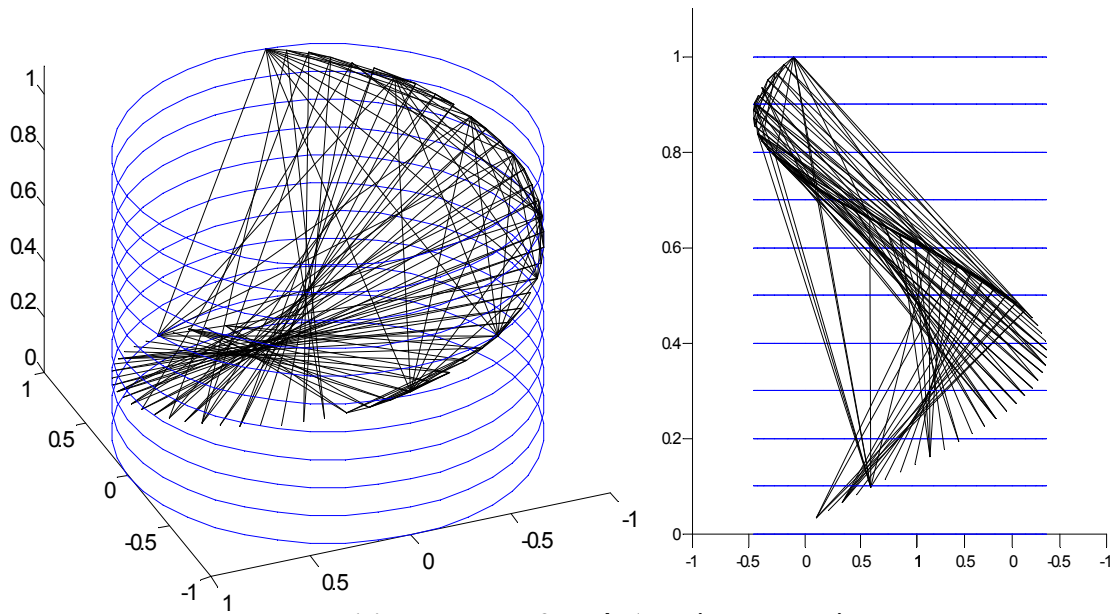
3. PLOTW

```

%script: plotW, plot 3D WORLD
%tic
axis([-1.2, 1.2, -1.2, 1.2, 0, 1.2]); stack, om=length(WW);
PX=zeros(om,1); PY=zeros(om,1); PZ=[1:om]; PZ=PZ/om;
angles=(2*pi/om).*[0:om];
for j=1:om, PX(j)=cos(angles(j)); PY(j)=sin(angles(j)); end

cor=zeros(om,4); cor(:, 1) = [1:om]'; cor(:, 2)=PX; cor(:, 3)=PY; cor(:, 4)=PZ;
for j = 1: om,
    fw= find(WW(j,:)); lfw=length(fw);
    for k=1: lfw
        kk=fw(k); if kk <=j ,
            X= [cor(j, 2) cor(kk,2)]; Y= [cor(j, 3) cor(kk,3)]; Z= [cor(j, 4) cor(kk,4)];
            pause(0.1); plot3 (X,Y,Z,'Color','black','LineWidth', 1 );
        end,
    end, pause(0.1);
end
%toc

```



Graphic output of plotw (animated)

Part 3: EVE

1. INIT

```
%open workspace
om=length(WW); P (1 : om, 3 ) = 1/om ;
angles=(2*pi/om).*[0:om-1];
% AR: arity
%AR=0;for i = 1:om , line = find ( WW (i , :) ); sl=length (line); AR(i)= sl; end
%for k=1:om, NUMBERS(k,1)= k , end;
```

2. P3D3

%PIG, script p3d3.m,

```
axis ([-1.1, 1.1, -1.1, 1.1, 0, 1.1]); hold on
%DISPLAY NUMBERS open p3d62.fig
```

```
LC=[1 1 0];
```

```
%t = input ( 'Enter pause between the cycles t ' ) % t=0.1 sec
tra=[]; % tra: trajectory
om=length(WW); AA=zeros(n,1); % AA contains subsequent actons
ain=a; %ain: storage of the initial acton;
PZ=[1:om]; PZ=PZ/om;
```

%%%%ARITY CALCULATION

```
%%%%%%for y=1:62, lfw=length(find(WW(y,:))); P(y,4)=lfw; end
```

%DISPLAY PARAMETERS IN FIGURE

```
%PAR12=['G=',num2str(G)];text (-1.2,-1.2, 1, PAR12); PAR12=['H=',num2str(H)];text
(-1.2,-1.2, 1.2,PAR12); PAR12=['C=',num2str(C)];text (-1.2,-1.2, 1,PAR12);
PAR12=['F=',num2str(F)];text (-1.2,-1.2, 0.9,PAR12); PAR12=['a=',num2str(aa)];text
(-1.2,-1.2, 0.8,PAR12); PAR12=['acton =',NAMES(aa,:)];text (-1.2,-1.2, 0.7,PAR12);
%PAR12=['n=',num2str(n)]; text (-1.2,-1.2 ,0.6,PAR12);
```

%%%%%%PURGE INITIAL PROBABILITIES P.

```
% P (1 : om, ) = 1/om ; % Equal probabilities.
% or : use script "init"
```

%%%% PREVIOUS ACTON DATA

P(1,3)=0; % empty word '!' cannot be selected

P(ain,3)=0; pra=ain; %pra : previous acton

% DISPLAY ain as green circle

text (0.9*(cos(angles(ain))), 0.9*(sin(angles(ain))), 0, 'o','color','green','FontSize',16);

for jj=1:n % MAIN LOOP BEGINS

% START ACTON SELECTION

select3

% END ACTON SELECTION

% ACTON ASTERISK DISPLAY; Randomization of the position of ASTERISK.

%RANDOMIZATION OF SIGN

u=rand/30; uu=rand; if uu<=0.5, uuu=1; else uuu=-1; end, u=u*uuu;

v=rand/30; vv=rand; if vv<=0.5, vvv=1; else vvv=-1; end, v=v*vvv;

%text ((cos (angles (a))+u) , (sin (angles(a))+v) , '*', 'color', [1 0 0], 'FontSize' ,18);

%pause(t),

text((cos(angles(a))+u),(sin(angles(a))+v),PZ(a),'*', 'color','red','FontSize',18);

pause(0.1),

%text (0.8*(cos (angles (a))+u) , 0.8*(sin (angles(a))+v) , '*', 'color', 'green',

'FontSize' ,18),

%!!!!!!!!!!!!!!!!!!!!!!

LLX= cos(angles(a))+u;

LLY= sin(angles(a))+v;

LLZ=PZ(a); LLC=[LLX LLY LLZ] ;

axis ([-1.2, 1.1, -1.1, 1.1, 0, 1.1]);

X1=LC(1); X2=LLC(1); Y1=LC(2); Y2=LLC(2); Z1=LC(3); Z2=LLC(3);

X=[X1 X2]; Y=[Y1 Y2]; Z=[Z1 Z2]; hold on,

plot3(X,Y,Z,'Color','red','LineWidth', 1);

LC=LLC ;

%END ASTERISK DISPLAY

% END OF PROTO FOLLOWS

AA (jj , 1) = a;

end

tra = AA';


```
PP=zeros(om,2); PP(:,1)=P(1:om,1); PP(:,2)=P(1:om,3);
```

```
%disp('type PP for probability distribution ');
%disp('type tra for trajectory ');
%disp(' '), disp(['total content ', num2str(ld)] );
%disp(['condensate size ', num2str(ld)] );
%disp(['JINI = ', num2str(JINI)]);
```

```
stack
```

3. SELECT3

```
%ACTON SELECTION
```

```
%START PROBABILITY DISTRIBUTION
```

```
pra=ain;
```

```
P(pra,3)=H*C ; % influence of former acton on neighbors; for calculating influence only
```

```
for k=1:om,
    INF=0; line = find ( WW (k , :) ); sl=length (line); ar= sqrt(sl);
    for j=1:sl, neighbor=line(j); INF=INF+ G*P(neighbor, 3)/ar; end,
```

```
%INFLUENCE
```

```
P(k,3)=P(k,3)- F * P(k,3 ) +INF;
```

```
end
```

```
P(a,3)= 0; P(1,3)=0; %P(a,3) reverted to 0
```

```
%END PROBABILITY DISTRIBUTION
```

```
% START ACTON SELECTION
```

```
%P(a,3)=0; %cannot be selected again
```

```
pra=a; % previous acton "a" remembered as "pra"
```

```
P(1,3)=0; SUM=0; ss=0; S=P(1:om , 3); SUM=sum(S);
```

```
P(1:om , 3)=P(1:om,3)/SUM;
```

```
%probabilities are normalized
```

```
r=rand; for i=1:om, ss=ss+P(i,3); if ss>r, a=i; break, end
```

```
end %NEW ACTON "a" HAS BEEN SELECTED
```

```
P(pra,3)=C; %new probability for former acton; now it can take part in next selection
```

```
%P(1,3)=0; % '1' and acton cannot be selected
```

```
% END ACTON SELECTION
```

4. NUMS

%%NUMERICAL ANALYSIS AND JINI

%nums calculates occurrence of a cell in the trajectory and Jini coeff.

% N(:,1) lists cells, N(:,2) lists occurrence

%open NAMES.mat;

DDA=[]; srt=sort(AA);

ls=length(srt); lss=ls-1; U=unique(AA); lu=length(U); N=zeros(lu,2);

N(:,1)=U; j=1; VV=0;

for k=1:lss, %over srt, except the last

if srt(k)==srt(k+1), VV=VV+1; else N(j,2)=VV+1; j=j+1; VV=0; end

end,

N(lu, 2)= VV+1;

ns=N(:,2)'; ns=sort(ns); lns=length(ns);

lms=length(ns); JIN=[1:lns]; JIN(1)=ns(1);

for k=2:lns, JIN(k)=JIN(k-1)+ ns(k); end,

SJ=sum(JIN); SE= (JIN(lns)*lu)/2; JINI=SJ/SE;

D=sortrows(N,2); NMS=NAMES(D(:,1),:); ld=length(D);

%D, lu, 'ns', ns, 'JIN', JIN, JINI

%N

%JIN

% ddn OCCURENCE DISTRIBUTION

disp(' '); disp('content:'); disp(' ');

DDA= D(:,1);

%base=D(:,1)'; NAMES(base,:) %display content names only

ldda=length (DDA);

%DISPLAY WORD No, OCCURRENCE, WORD

for i = 1:ldda , disp ([num2str(i), ' ', num2str(D(i,1)),',', num2str(D(i,2)),' ',

NAMES(D(i,1), :)]), end

%for i = 1:ldda , disp ([num2str(D(i,2)),' ', NAMES(D(i,1), :)]), end

cont=D(:,1); content=sort(cont);

%for f=1:ldda, disp ([num2str(TT(f)),',', num2str(TT(f,2)),' ', NAMES(AA(f,1), :)]), end

%disp(' '), disp(['total content ', num2str(ld)]); disp(['JINI = ', num2str(JINI)]);

5. SAYCON2

```
% Program saycon2 as script, can be used as function(content,connector)
% saycon = "say_con(content,connector)"
```

%Part 1: SPLIT: splcomplex cells

```
    %lists content , builds structure SPLIT: name, nleft, nright
    %splits composite name into component NAMES

wl=[];wm=[];wr=[];d=1;
lcnt=length(content); SPLIT(1).name=[]; SPLIT(1).nleft=[]; SPLIT(1).nright=[];

    for k=1:lcnt, SPLIT(k).name= cellstr(NAMES(content(k,:),));
    end;
% SPLIT( : , : ).name generates list of names;
fst=[]; %for find str
    %sspl=size(SPLIT); ssp=sspl(2);
csp=0;

for k=1:lcnt, fst= findstr ( ' ', char( SPLIT(k).name) ); %find space between components
    %if no space:
    if isempty(fst)==1, SPLIT(k).nleft=char( SPLIT(k).name); SPLIT(k).nright=[]; %only
left component
    %if space
    else csp=char( SPLIT(k).name); lcsp=length(csp); %total NAME
        SPLIT(k).nleft=csp(1:(fst-1)); SPLIT(k).nright =csp((fst+1):lcsp);fst=[];
    end,
end
end
```

%Part 2: CONDENSATE

```
disp ( ' '); disp('condensate:'); disp ( ' ');

    TRIPLET(1).L=[]; TRIPLET(1).R = []; TRIPLET(1).M=[];
    TRIPLET(1).TRI=[];
    TRI1 = ['_','_','_','_','_','_','_'];
    nt=0; nnt=0;
for c=1:lcnt,

    for m=(1:lcnt),
```

```

dd= isequal( SPLIT(c).nleft, SPLIT(m).nright);
    if dd==1,      d=d+1;
    wl=SPLIT(m).nleft; wr=(SPLIT(c).nright); wm =(SPLIT(c).nleft); else

    TRI2= [wl,'_',wm,'_', wr, ' ; '];
    end,

tt=isequal (TRI1,TRI2); % if not and if wr not empty :
    if tt==0,  ttt=isempty(wr) ;
        if ttt==0,
            NC=[wl,' ', wm,]; NM=[wm,' ', wr,];
            %NC=char( SPLIT(c).name);
            [tfc, locc] =ismember ( NC, NAMES, 'rows');
            %NM=char( SPLIT(m).name);
            [tfm, locm] =ismember ( NM, NAMES, 'rows');

            if abs(locc-locm)<=5,

% 5 is the range of narrow condensate

% NARROW CONDENSATE IS MARKED WITH ASTERISK
            nnt=nnt+1; disp([TRI2, ' * ']), else
            disp (TRI2),
            %disp([ wl,'_',wm,'_', wr, ' ; ']) ,
            end
            nt=nt+1;
            end,

            TRI1=TRI2;
            end, %if tt==0,

    TRIPLET(d).L =wl; TRIPLET(d).R = wr; TRIPLET(d).M = wm; %for a record
    TRIPLET(d).TRI = [TRIPLET(d).L,'_',TRIPLET(d).M,'_', TRIPLET(d).R, ' ; '];

    end, %for m=(1:lcnt)

end %for c=1:lcnt,

disp(' '), disp(['total content ', num2str(ld)] );
disp(['condensate ', num2str(nt)]);disp(['narr. cond.', num2str(nnt)]);
disp(['JINI = ', num2str(JINI)]); disp(['cond/cont = ', num2str(nt/ld)]);
disp(['nr.cnd/cnt = ', num2str(nnt/ld)]);

```

5A. SAY_CON

```
% Program say_con as script, can be used as function(content,connector)
%function say_con = say_con(content,connector)

%Part 1: SPLIT: splcomplex cells
    %lists content , bids structure SPLIT: name, nleft, nright
    %splits name into components
    wl=[];wm=[];wr=[];d=1;
    lcnt=length(content); SPLIT(1).name=[]; SPLIT(1).nleft=[]; SPLIT(1).nright=[];

    for k=1:lcnt, SPLIT(k).name= cellstr(NAMES(content(k,:))); end;
    % SPLIT( : , : ).name generates list of names;
    fst=[]; %for find str
    sspl=size(SPLIT);
    ssp=sspl(2);
    csp=0;

    for k=1:lcnt, fst= findstr ( ' ', char( SPLIT(k).name) ); %find space between components

    if isempty(fst)==1, SPLIT(k).nleft=char( SPLIT(k).name); SPLIT(k).nright=[]; %only
    left component

    else csp=char( SPLIT(k).name); lcsp=length(csp);

    SPLIT(k).nleft=csp(1:(fst-1)); SPLIT(k).nright =csp((fst+1):lcsp);fst=[];
    end, end

%Part 2: DOUBLETS AND TRIPLETS
    disp ( ' ');
    disp('condensate:');
    disp ( ' ');

% CONDENSATE SIZE %%%%%%%%%%

    TRIplet(1).L=[]; TRIplet(1).R = []; TRIplet(1).M =[];
    TRIplet(1).TRI=[];
    TRI1 = ['_','_','_','_','_','_','_'];
    nt=0;
    for k=1:lcnt, mm= 1;
```

```

for m=((mm+1):lcnt),

dd= isequal( SPLIT(k).nleft, SPLIT(m).nright);
if dd==1,      d=d+1;
wl=SPLIT(m).nleft; wr=(SPLIT(k).nright); wm =(SPLIT(k).nleft); else

TRI2= [wl,'_',wm,'_', wr, ' '];
end,

tt=isequal (TRI1,TRI2); if tt==0,   ttt=isempty(wr) ; if ttt==0,   disp(TRI2);nt=nt+1;
    %%%%%%%%%%%
TRI1=TRI2; end, end
TRIplet(d).L =wl; TRIplet(d).R = wr; TRIplet(d).M = wm; %for a record
TRIplet(d).TRI = [TRIplet(d).L,'_',TRIplet(d).M,'_', TRIplet(d).R, ' '];

end, end
disp(' '), disp(['total content ', num2str(ld)] );
disp(['condensate ', num2str(nt)])
disp(['JINI = ', num2str(JINI)]); disp(['cond/cont = ', num2str(nt/ld)]);

```

6. STACK

```

%script: stack
ZZ=zeros(1,41); tt=0;
for zz=0:0.1:1
    t = 0:pi/20:(2*pi); ZZ(1,:)=zz; tt=ZZ;
    plot3(sin(t),cos(t),tt), hold on, tt=tt+1;
end, axis ([-1, 1, -1, 1, 0, 1.1]);

```

7. TR

```

%tr  replays TRAJECTORY as NAMES
% compare with tr3d, which replays 3D TRAJECTORY IN TIME
%compare with repro: 3D TRAJECTORY IN SPACE ; replays AA trajectory in
WORLD

%NUMBERS AND WORDS
ltra=length (AA); for i = 1:ltra   ntr = AA(i);  disp ([num2str(i),' ', num2str(ntr),' ',
NAMES(ntr,:)]) , end

%NUMBERS
% ltra=length (tra); for i = 1:ltra   ntr = tra(i); disp ([num2str(i),' ', num2str(ntr)]) , end

```

```

% TRAJECTORY TO SAVE AS TT
T=zeros(2,n); ltra=length (AA); ntr=0; for i = 1:ltra  ntr = AA(i); T(1,i)= i; T(2,i) = ntr;
end, TT= T';

```

8. TR3D

```

% tr3d : replays AA as 3D TRAJECTORY IN TIME
% compare with tr : replays TRAJECTORY as NAMES
%compare with repro:
%3D TRAJECTORY IN SPACE ; replays AA trajectory in WORLD

```

```

n=length(AA); om=length(WW);
h=2; %height
figure, axis ([-1.4, 1.4, -1.4, 1.4, 0, 2.1]); view(-160, 55),hold on,
%DISPLAY NUMBERS
for zz=0:0.2:h, t = 0:pi/20:(2*pi); ZZ(1,:)=zz; tt=ZZ;
    plot3(sin(t),cos(t),tt), hold on, tt=tt+1; end

```

```

zz=2/n;
X0=[cos(angles(ain)) cos(angles(AA(1)))];
Y0=[sin(angles(ain)) sin(angles(AA(1)))];
Z0=[0 zz];

```

```

plot3(X0,Y0,Z0,'Color','black','LineWidth', 1 );

```

```

pause(0.1);
nn=(n-1);
for k=(1:nn),

```

```

X=[cos(angles(AA(k))) cos(angles(AA(k+1)))];
Y=[sin(angles(AA(k))) sin(angles(AA(k+1)))];
Z=[zz*(k) zz*(k+1) ];

```

```

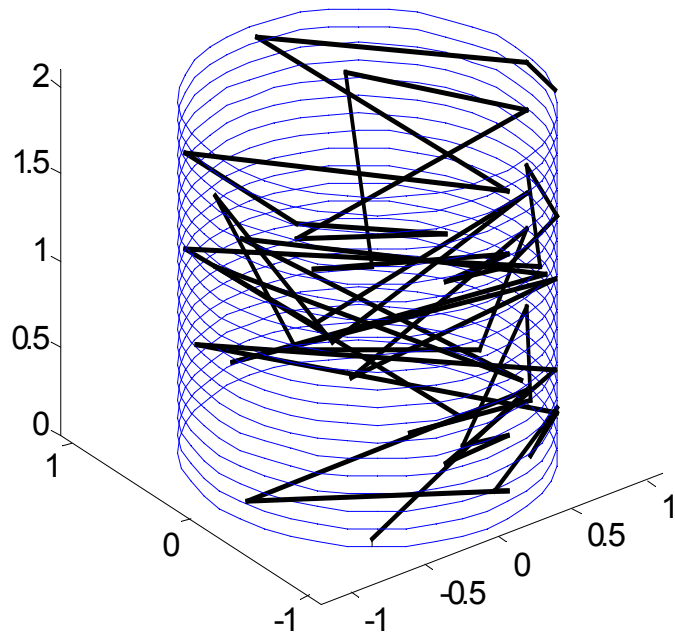
plot3 (X,Y,Z,'Color','black','LineWidth', 2 ); hold on

```

```

pause(0.1);
end
for j=1:om, text ( 1.15*cos ( angles (j) ) , 1.15*sin (angles(j)) , num2str(j),'FontSize', 8),
end

```



Graphic output of tr3d

9. REPRO replays AA (trajectory)

EXAMPLE OF INPUT:

ENTER:

```
AA=[ 41 62 34 49 48 57 51 55 21 58 45 49 46 62 51 43 46 19 50 17 60 33
58 40 62 47 37 19 39 62 38 28 52 62 56 49 45 49 38 41 11 62 37 45 37 28
49 16 62 58]; repro;
[ENTER]
```

REPRO.m

```
%repro: 3D TRAJECTORY IN SPACE ; replays AA trajectory in WORLD
% compare with tr3d, which replays 3D TRAJECTORY IN TIME
%compare with tr, which replays TRAJECTORY as NAMES

cd C:\MATLAB6p5\work\PIG; load NAMES.mat, load WW.mat,
n=length(AA);ain=AA(1);nn=n-1; om=length(WW); zz=1/om;

angles=(2*pi/om).*[0:om-1]; ZV=[0 : zz : 1];%COORDINATES
```



```
omm=om-1; figure, stack, axis ([-1.2, 1.2, -1.2, 1.2 , 0, 1.1]); view(-160, 55),
```

%DISPLAY NUMBERS

```
%for j=1:om, text ( 1.1*cos ( angles (j) ) , 1.1*sin (angles(j)) , num2str(j),'FontSize', 8),  
end
```

```
%"ain" display
```

```
text (0.9*(cos(angles(ain))), 0.9*(sin(angles(ain))), 'o','color', 'green','FontSize',20 );
```

%ASTERISK AND LINE DISPLAY;

```
for jj=1:nn ; a1=AA(jj); a2=AA(jj+1);
```

```
    % Randomization of the position of ASTERISK.
```

```
        u=rand/25; uu=rand; if uu<=0.5, uuu=1; else uuu=-1; end, u=
```

```
        v=rand/25; vv=rand; if vv<=0.5, vvv=1; else vvv=-1; end, v=v*vvv;
```

```
        w=rand/25; ww=rand; if ww<=0.5, www=1; else www=-1; end, w=w*www;
```

```
    %ASTERISK
```

```
        text (0.9*(cos(angles(a2))+u), 0.9*(sin(angles(a2))+v), (ZV(a2)+w),'*','color',  
'red','FontSize',14 );
```

```
        pause(0.1), hold on %
```

%LINE

```
        X1=0.9*cos(angles(a1))+u; Y1=0.9*sin(angles(a1))+v; Z1=ZV(a1)+w;
```

```
        X2=0.9*cos(angles(a2))+u; Y2=0.9*sin(angles(a2))+v; Z2=ZV(a2)+w;
```

```
        X=[X1 X2]; Y=[Y1 Y2]; Z=[Z1 Z2];
```

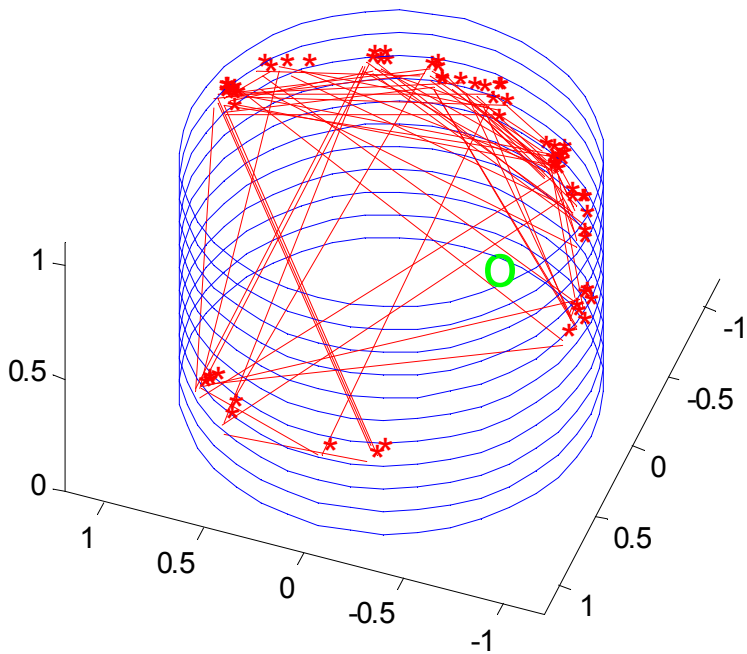
```
        plot3(X,Y,Z, 'Color','red','LineWidth',1,'LineStyle','-'); hold on,
```

% END ASTERISK AND LINE DISPLAY

```
end %jj;
```

```
disp([' n: ', num2str(n), ' initial acton: ', num2str(ain)] )
```

```
disp('run tr for TRAJECTORY with names, type tr3d, for 3D TRAJECTORY')
```



Graphic output of repro

10. REPRO2D , requires WW.mat and NAMES.mat

```
%repro2d: 2D distribution of actons over NAMES
% compare with tr3d, which replays 3D TRAJECTORY IN TIME
%compare with tr, which replays TRAJECTORY as NAMES

n=length(AA);ain=AA(1);nn=n-1; om=length(WW);
angles=(2*pi/om).*[0:om-1]; %COORDINATES
figure, axis([-1.2, 1.2, -1.2, 1.2]); hold on
t = 0:pi/20:(2*pi); plot(sin(t),cos(t)),

%DISPLAY NUMBERS
for j=1:om, text ( 1.1*cos ( angles (j) ) , 1.1*sin (angles(j)) , num2str(j),'FontSize', 8), end

%"ain" display
text ((cos(angles(ain))), (sin(angles(ain))), 'o','color', 'green','FontSize',20 );

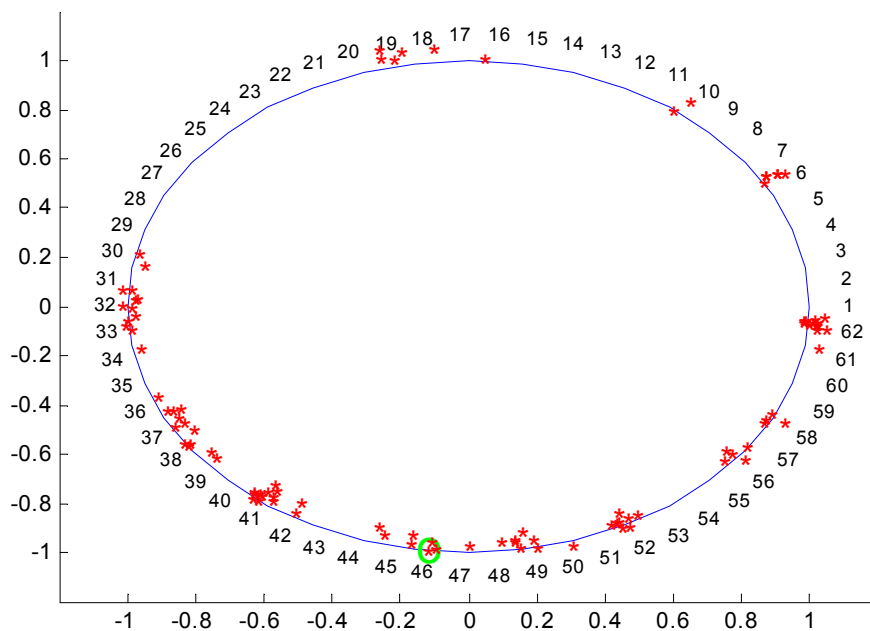
%ASTERISK AND LINE DISPLAY;
for jj=1:nn ; a1=AA(jj); a2=AA(jj+1);
```

```

% Randomization of the position of ASTERISK.
u=rand/25; uu=rand; if uu<=0.5, uuu=1; else uuu=-1; end, u=
v=rand/25; vv=rand; if vv<=0.5, vvv=1; else vvv=-1; end, v=v*vvv;
%ASTERISK
text ((cos(angles(a2))+u), (sin(angles(a2))+v), '*', 'color', 'red', 'FontSize', 14 );
pause(0.1), hold on %
%LINE , OPTIONAL
%X1=cos(angles(a1))+u; Y1=sin(angles(a1))+v; X2=cos(angles(a2))+u;
Y2=sin(angles(a2))+v;
%X=[X1 X2]; Y=[Y1 Y2]; plot(X,Y, 'Color','red','LineWidth',1,'LineStyle','-'); hold
on,

% END ASTERISK AND LINE DISPLAY
end %jj;
disp([' n: ', num2str(n), ' initial acton: ', num2str(ain)] )
disp('run tr for TRAJECTORY with names, type tr3d, for 3D TRAJECTORY')

```



Graphic output of repro2d

Part 4

Example of a batch command

```
>> C = 0.5; G = 1; H = 0.8; F = 0.8;
init, n=25
a=22; figure, stack, view(-160, 55),
p3d3, disp(' '); disp(['AA=[' , num2str(AA'), ']; ']),
nums, say_con, disp(['ain ', num2str(ain), ', a fin ' num2str(a)]),

n=25;
figure, stack, view(-160, 55),
p3d3, disp(' '); disp(['AA=[' , num2str(AA'), ']; ']),
nums, content=D(:,1)'; say_con,
disp(['ain ', num2str(ain), ', a fin ' num2str(a)])
```

Part 5 Structure of WORLD (62 x 62)

AR: Arity

No.	NAME	Neighbors (No.)	Neighbors (NAMES)	AR
1	!	0	!	0
2	sow	29, 30, 35, 36	sow old , sow pig , sow poor , sow sent	4
3	old	29	sow old	1
4	pig	30, 31, 32, 33, 34	sow pig , pig three , first pig , second pig , third pig	5
5	three	31	pig three	1
6	first	32, 37, 41, 45, 49, 52, 56, 62	first pig, sent first, first meet, first say , give first, first build, ask first, eat first	8
7	second	33	second pig	1
8	third	34	third pig	1
9	poor	35	sow poor	1
10	sent	36, 37, 38, 39	sow sent , sent first, sent away , sent seek ,	4
11	away	38	sent away	1
12	seek	39, 40	sent seek , seek fortune	2
13	fortune	40	seek fortune	1
14	meet	41, 42	first meet, meet man	2
15	man	42, 43, 46, 47	meet man , man bundle, say man , man give	4
16	bundle	43, 44	man bundle, bundle straw	2
17	straw	44, 48, 50	bundle straw, give straw, straw build ,	3
18	say	45, 46, 58	first say , say man , say no	3
19	give	47, 48, 49	man give , give straw , give first	3
20	house	51, 54, 60	build house , come house , blow house	3
21	build	50, 51, 52	straw build , build house , first build	3
22	wolf	53, 55, 59, 61	wolf come , wolf ask , wolf blow , wolf eat	4

23	come	53, 54	wolf come , come house	2
24	ask	55, 56, 57	wolf ask, ask first, ask enter	3
25	enter	57	ask enter	1
26	no	58	say no	1
27	blow	59, 60	wolf blow, blow house	2
28	eat	61, 62	wolf eat, eat first	2
29	sow old	2, 3, 30, 35, 36	sow , old , sow pig , sow poor , sow sent	5
30	sow pig	2, 4, 29, 31, 32 , 33, 34, 35, 36	sow , pig , sow old , pig three , first pig , second pig , third pig , sow poor , sow sent	9
31	pig three	4, 5, 30, 32, 33, 34	pig , three , sow pig , first pig , second pig , third pig	6
32	first pig	4, 6, 30, 31, 33, 34, 37, 41, 45, 49, 52, 56, 62	pig , first , sow pig , pig three , second pig , third pig , sent first , first meet , first say , give first , first build , ask first , eat first	13
33	second pig	4, 7, 30, 31, 32, 34	pig , second , sow pig , pig three , first pig , third pig	6
34	third pig	4, 8, 30, 31, 32, 33	pig , third , sow pig , pig three , first pig , second pig	6
35	sow poor	2, 9, 29, 30, 36	sow , poor , sow old , sow pig , sow sent	5
36	sow sent	2, 10, 29, 30, 35, 37, 38, 39	sow , sent , sow old , sow pig , sow poor , sent first , sent away , sent seek	8
37	sent first	6, 10, 32, 36, 38, 39, 41, 45, 49, 52, 56 12, 62	first , sent , first pig , sow sent , sent away , sent seek , first meet , first say , give first , first build , ask first , eat first	12
38	sent away	10, 11, 36, 37, 39	sent , away , sow sent , sent first , sent seek	5
39	sent seek	10, 12, 36, 37, 38, 40	sent , seek , sow sent , sent first , sent away , seek fortune	6
40	seek fortune	12, 13, 39	seek , fortune , sent seek	3
41	first meet	6, 14, 32, 37, 42, 45, 49, 52, 56, 62	first , meet , first pig , sent first , meet man , first say , give first , first build , ask first , eat first	10
42	meet man	14, 15, 41, 43, 46, 47	meet , man , first meet , man bundle , say man , man give	6
43	man bundle	15, 16, 42, 44, 46, 47	man , bundle , meet man , bundle straw, say man , man give	6
44	bundle straw	16, 17, 43, 48, 50	bundle , straw , man bundle , give straw , straw build	5
45	first say	6, 18, 32, 37, 41, 46, 49, 52, 56, 58, 62	first , say , first pig , sent first , first meet , say man , give first , first build , ask first , say no , eat first	11
46	say man	15, 18, 42, 43, 45, 47, 58	man , say , meet man , man bundle , first say , man give , say no	7
47	man give	15, 19, 42, 43, 46, 48, 49	man , give , meet man , man bundle , say man , give straw , give first	7
48	give straw	17, 19, 44, 47,, 49, 50	straw , give , bundle straw, man give , give first , straw build	6
49	give first	6, 19, 32, 37, 41, 45, 47, 48, 52, 56, 62	first , give , first pig , sent first , first meet , first say , man give , give straw , first build , ask first , eat first	11
50	straw build	17, 21, 44, 48, 51, 52	straw , build , bundle straw, give straw , build house , first build	6
51	build house	20, 21, 50, 52, 54, 60	house , build , straw build , first build , come house , blow house	6
52	first build	6, 21, 32, 37, 41, 45, 49, 50, 51, 56,	first , build , first pig , sent first , first meet , first say , give first , straw build , build	11

		62	house , ask first , eat first	
53	wolf come	22, 23, 54, 55, 59, 61	wolf , come , come house , wolf ask , wolf blow , wolf eat	6
54	come house	20, 23, 51, 53, 60	house , come , build house , wolf come , blow house	5
55	wolf ask	22, 24, 53, 56, 57, 59, 61	wolf , ask , wolf come , ask first , ask enter , wolf blow , wolf eat	7
56	ask first	6, 24, 32, 37, 41, 45, 49, 52, 55, 57, 62	first , ask , first pig , sent first , first meet , first say , give first , first build , wolf ask , ask enter , eat first	11
57	ask enter	24, 25, 55, 56	ask , enter , wolf ask , ask first	4
58	say no	18, 26, 45, 46	say , no , first say , say man	4
59	wolf blow	22, 27, 53, 55, 60, 61	wolf , blow , wolf come , wolf ask , blow house , wolf eat	6
60	blow house	20, 27, 51, 54, 59	house , blow , build house , come house , wolf blow	5
61	wolf eat	22, 28, 53, 55, 59, 62	wolf , eat , wolf come , wolf ask , wolf blow , eat first	6
62	eat first	6, 28, 32, 37, 41, 45, 49, 52, 56, 61	first , eat , first pig , sent first , first meet , first say , give first , first build , ask first , wolf eat	10

=====.

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[email](#)

PATTERN CHEMISTRY OF LANGUAGE

Yuri Tarnopolsky

The links presented here refer to a series of e-publications PATTERN CHEMISTRY OF LANGUAGE. It is an attempt to apply Pattern Theory of Ulf Grenander (Brown University; see numerous [links](#) on the Web) to the atomistic aspects of language. While Pattern Theory is a **mathematical** discipline, Pattern Chemistry is a small contribution to its big domain by a **chemist** with a close connection to Ulf Grenander's work and a lifelong interest in languages, some as different as Russian, Hebrew, Japanese, and Hungarian, apart from main European ones.

The story of this series should better be told from the first person.

I am an organic chemist, Ph.D., who happened to have a lot of spare time to think about matters outside my immediate profession. In the late 1970s, when the political atmosphere in Soviet Russia was growing tenser by the day, I was especially intrigued by the problem of stability of social structures and the further fate of the strained social system. Much later, this direction of thought resulted in "[History as Points and Lines](#)," initiated and co-authored by Ulf Grenander. The same question of stability can be asked about the structures of language in the process of historical evolution as well as individual language acquisition.

In 2002, I ran into *The Atoms of Language* by Mark C. Baker. I took his question "what if the words were atoms" completely serious, which was quite natural in the framework of Pattern Theory. That was the initial impetus to the current line of work.

Contrary to a wide spread view, chemistry is not just a description of millions of substances and their transformations. The central organizing idea of chemistry, borrowed from physics, is that between an initial stable state of atoms connected in a particular way, and the final stable state of the same atoms connected in a different way, there is an unstable fleeting state of transition (transition state) from one to the other. The second theoretical idea is that if we have a structure of atoms connected with bonds in a certain order, then any other arrangement of the same atoms can emerge spontaneously. In fact, chemical reactions result in only a few products because the rest of transformations are negligibly slow. The third idea is that the speed of transformation depends on the height of the transition barrier between the initial and final state. Pattern Theory provides a measure of the stability of abstract structures of any origin, including those of thought and its expression.

Obviously, these ideas can be easily generalized over other objects built of atomic entities and connections between them, such as structures of language. Pattern Theory from the point of view of a chemist is exactly this kind of generalized chemistry. If applied to

language, Pattern Chemistry regards its generation and evolution as a natural process governed by relative stability and kinetics of linguistic structures.

Pattern Theory of Ulf Grenander studies structural complexity regardless of interdisciplinary boundaries. It reduces structure to a set of atomic entities (generators) selectively connected by bonds, thereby representing observable objects of widest variety, including language and thought. The unusual aspect of Pattern Theory is its metrics which allows for distinguishing between more and less stable (i.e., probable) structures. **Pattern Chemistry** focuses not so much on stable structures as on the fleeting transition states between them, similarly to the way chemistry treats molecular transformations, making distinction between fast and slow transformations.

The parallel between linguistics and chemistry has been a standard explanatory model since the discovery of the DNA's structure and its ability to carry a protein "meaning." Besides, chemistry uses a particular language (chemical nomenclature) to convert complex non-linear structures ("chemical thoughts") into a linear word which can potentially be communicated through speech.

The central ideal of Pattern Chemistry is that **complexity** in nature and society evolves **from simple** states **by simple steps**. This perspective of complexity differs from the concept of dynamic complexity represented by systems of differential equations in the so-called "order-from-chaos" theories. Indeed, this is an "order-from-order" concept, more in line with the Darwinian paradigm of evolution. It seems interesting to investigate language acquisition, generation, and evolution in the discrete stepwise way, which is very similar to both ontogenesis/phylogenesis in biology and chemical transformations.

Thus, e-papers SALT and SALT 2 explore the stepwise extraction of grammar from the text of the Hungarian folk tale "Salt," basing on extremely simple rules. I used the Hungarian text in order to eliminate all semantic associations natural for a native speaker of English and to emphasize the universality of the model regardless of grammar and vocabulary.

The most recent e-publication in this collection, entitled, maybe too ambitiously, PATTERN CHEMISTRY OF THOUGHT AND SPEECH, comes closer to the evolutionary problems that any of the preceding ones.

Human thought is not directly observable, apart from vague shadows in brain scans. We simply do not know what it is. We have nothing to support the belief that we think in linear sequences of whatever units, but we definitely speak in them. Moreover, the syntactic trees are definitely non-linear. The paper further explores a hypothetical protolanguage, called Nean, in which the simple elementary thought consisting of two connected entities directly translates into the simplest elementary phrase consisting of two words. Nean, unlike extant languages, is topologically identical with thought.

Neon sounds like a repetitive random series of elementary doublets. Two doublets with common element can be combined into linear triplets. The e-paper explores the ability of this inherently linear and primitive language to express more complex non-linear thoughts by means of the process of linearization. It appears that Neon, subjectively, is quite expressive, in spite of its primitiveness.

I present a computer simulation, based on simple principles, which represents thinking and speech as competition of alternative thought structures for a spot in consciousness and further generation of linear speech-ready expressions longer than elementary doublets. I use the story of the Three Little Pigs as the substrate of the process and discuss the potential of Neon for further complexification and grammaticalization.

I regard Neon as a point of evolutionary divergence between thought and speech, both initially linear, after which a variety of non-linear grammars can emerge. The current collection of e-papers, or, rather, essays, illustrates the way to this idea, starting from MOLECULES AND THOUGHTS.

Kinetics is the study of speed. In short, the main idea is: we say what we can say **faster** and we say **faster** what we can **faster** convert from nonlinear thought into linear speech.

Unlike distant worlds and invisible atoms, language is as directly observable, rich, and exciting as the beauty of nature. Not accidentally so many outsiders felt the irresistible pull of linguistics and tried their mind in solving its puzzles. I believe that the current collection, coming from remote outskirts of linguistics, can illuminate the problems of evolutionary linguistics and intimate mechanisms of verbal communication from a kinetic angle and in chemical light.

NOTE: The kinetic direction has already been tested in linguistics by Martin Nowak *et al* who invoked the fundamental idea of competitive kinetic evolution (Manfred Eigen).

LINKS

1. [Molecules and Thoughts: Pattern Complexity and Evolution in Chemical Systems and the Mind](#) , 2003 (or [this](#) and [this](#)).
2. [TIKKI TIKKI TEMBO and the Chemistry of Protolanguage](#) , 2004 (or [this](#)).
3. [Pattern Theory and “Poverty of Stimulus” Argument in Linguistics](#) ,2004 (or [this](#)) .
4. [The Three Little Pigs : Chemistry of language acquisition](#) ,2005 (or [this](#)).

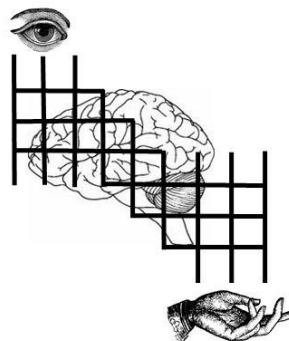
5. [Salt: The Incremental Chemistry of Language Acquisition](#) , 2005 (or [this](#)).
6. [Salt 2: Incremental Extraction of Grammar by Simplistic Rules](#) , 2005 (or [this](#)).
7. [The Chemistry of Semantics](#) , 2005 (or [this](#)).
8. [Do Pirahã speak Nean?](#) , 2007 (or [this](#)) .
9. [PATTERN CHEMISTRY OF THOUGHT AND SPEECH](#) , 2010 (also [here](#)) .
- 9A . APPENDIX to PATTERN CHEMISTRY OF THOUGHT AND SPEECH:
[MATLAB codes](#) , (also [here](#)) .

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MAIN PAGE: <http://spirospero.net/complexity.htm>

HOME PAGE: <http://spirospero.net>

November, 2010



Pattern chemistry of the origin of mind

Yuri Tarnopolsky

This project evolves

In this essay I attempt to formulate a hypothetic mechanism of spontaneous emergence of complex systems. I take mind as a typical example. Other possible particular cases range from the origin of planets to human history and, to jump down the scale, human individuality. By complex system I mean *exsystem*: Evolving Complex **SYSTEM**.

The conceptual foundation for treating such “too big to succeed” problems is Pattern Theory (Ulf Grenander), which represents the abstract structure mathematically, i.e., regardless of tangible properties yet never losing touch with reality.¹

I cannot give here even a short review of the principles of Pattern Theory except for saying that from the point of view of a chemist it is a perfect abstract chemistry of anything consisting of atomic **entities** (generators) and **connections** (bonds) between them, with probabilities (or energies) attributed to either. Patterns are open-ended collections of similar **configurations**.² Such configurations are exemplified by molecules. What I call pattern chemistry deals with intimate mechanisms of transformations of configurations. I list major sources in **Appendix 1**.

¹ Two most relevant and more accessible books by Ulf Grenander are *Elements of Pattern Theory* (1996) and *A Calculus of Ideas* (2012).

² Groups under similarity transformation on a set of configurations.

I can skip introductory explanations because I start *ab ovo* and use mostly visual representation typical for chemistry and engineering. As a chemist, I perceive the world in terms of atomic entities (generators of Pattern Theory or atoms of chemistry) and connections between them. This can be expressed as a connectivity matrix, but I prefer to visualize not only the structure but also the process of its construction, as if it were a machine or a bridge.

In **Appendix 2**, I tell the story of the origin of this essay. I do it because the best way to understand something is either to build it or to study its history. For such intriguing exsystems like life, mind, and society building is not an option.

The most important circumstance in my story is that I am neither a mathematician, nor computer scientist, nor a historian but just a chemist with wide interests outside my field. In my current field of pattern chemistry I am alone and without any need of grants, peer reviews, and tenure can frolic as wild as it gets. Regarding Pattern Theory, however, I have been lucky to enjoy discussions with Ulf Grenander, as well as his attention and support, for a long time.

PART ONE: HISTORY AS EXPLANATION

THE PROBLEM

The origin of the problem of spontaneous emergence predates recorded human history. It generated mythological and religious explanations, practically all being description of making or building by a mythological figure. The scientific inquiry seems to get a start by the first half of the twentieth century when theoretical physicists began to ask two separate questions:

Question 1. How is life physically possible?

Question 1 was answered in a very general form by Erwin Schrödinger (1887-1961) in [*What is life? The Physical Aspect of the Living Cell*](#) (1944). The modern answer, shaped by Ilya Prigogine (1917-2003) in the second half of the twentieth century, describes life as a dissipative structure far from equilibrium, which needs a constant supply of free energy.³

³ Free energy is directly convertible into work, as, for example, chemical energy, light, and electricity, but not heat.

Question 2. Since life is so complex and spontaneous origin of complex systems is improbable, how could it spontaneously emerge?

Question 2 implies two plausible assumptions, which I share.

2A. Life is complex.

2B. Spontaneous origin of complex systems is improbable.

Both questions 1 and 2, in my opinion, demonstrate what I call synchronic approach, which I do not share: origin is considered a single event with a beginning and an end. Yesterday there was no life and today—bang!—it is here. There is, however, a different—diachronic—approach, which I prefer: origin is a sequence of events lining up as the history of the object, in our case, still ongoing. It is always debatable which event can be called origin, where the sequence ends, and whether it ends at all.

Simple objects, I presume, do not necessarily exhibit anything long enough to be called history. They can emerge spontaneously because probability of a conjunction of a few favorable conditions can be substantial. Not only that, but simple systems can go through the same states again and again in the same or different order with the same average probability of each state⁴. Thus, a chemical transformation occurs spontaneously because it involves a few atoms and bonds. Even if the molecule is very big and if we somehow label individual atoms, they bond and split indefinitely in equilibrium. A large complex structure, however, can appear only once, diachronically, and in a sequence of simple steps. Origins of planets and of humanity on one of them seem to be two extreme examples of diachronicity. Next, I will consider something less grand than either of them.

EVENT AND PROCESS

While we can understand many physical, chemical, and biological objects and systems *per se* regardless of their origin and history, to understand what society and civilization are at a certain point requires significant knowledge of how they looked some time before that. The fresh example, while I am writing this (October, 2012), is the US Presidential

⁴It is called ergodicity. Exsystems cannot be ergodic. They emerge, grow, decline, and die only once.

Elections. To understand what is going on in 2012, we need to go back to Elections 2008 and further back to at least 1994, the beginning of the Republican Revolution.

Understanding is a process in the mind, a kind of intense, sometimes stressful small-scale evolution. To understand means to come to a relaxed stable state of mind when no big questions remain. Once we have understood something, we normally cannot un-understand it.

With the yearbook of history opened on page 1994 we would still have important questions about the origin of the Republican Revolution and would have to go back to the Franklin D. Roosevelt Revolution better known as the New Deal, to which the former is, probably, a counter-revolution asking for a new revolution—a typical pattern of history.

Some questions could be addressed to even earlier periods, and the American Civil War is most relevant. What is important, the more and more distant past would be **less and less relevant** to the initial question about Elections 2012. Some elementary knowledge of world history will do, while the origin of life and humans on earth would be completely irrelevant, unless in the obscurantist politics of the religious right. This is the essence of diachronic analysis.

How the mind originated and how it works is a subject of tens or hundreds of thousands printed and digital pages. The encyclopedic [How the Mind Works](#) by Steven Pinker (1997), is over 650 pages long consists mostly of words and begins with the honest “we don’t understand how the mind works.” The book of [the same title](#) by Carlo Lazzari (2007), 121 pages, contains mathematical and graphic material, symbolically, with lots of white space. Daniel Kahneman’s “Thinking Fast and Slow”⁽²⁰¹¹⁾, almost 500 pages, is about how foolish a mind can be, and has just a couple of charts.

Science of the mind is a very large, complex, diverse, fragmented, and unsettled subject, itself in the process of fast evolution. Some central terms still remain undefined and crucial problems unsolved, which makes it all the more interesting. I am not going into details here, however. With so much money on modern mind, for the mind to understand itself is like to win a basketball game on full stomach.

Recently, I have bumped into the ongoing study of the little worm *C. elegans*, including the details of its behavior and **connectome**—the map of connections between the cells of nervous system. It was an additional stimulus to go back to my old idea. The connectome research, very high tech, goes far beyond simple creatures, embracing brains of humans and even their babies.⁵ I think that there could be a way to test the ideas of this essay not only on the worm, but also on other detailed records of evolution, such as history. See **Appendix 3**.

My pattern of thinking is entirely chemical and engineering in nature, which is different from the way most mathematicians and physicists think. It also has poetic elements, like the habit of metaphor, which makes me feel at home among patterns. This is the only

⁵ See a remarkable [video](#) as an introduction to the field.

natural way for me and I will do it in my ideographic manner: by drawing pictures on the sand with a twig. Same applies to the style. Patterns and metaphors do not know borders. And if I go overboard sometimes, so be it.

CONTAMINATION BY MIND

I am interested in a highly general and abstract problem: the origin of complexity from simplicity. It resonates, in a pattern way, with the reversed ancient [paradox “heap.”](#)

Direct version: *1,000,000 grains of sand is a heap of sand* (Premise 1)
 A heap of sand minus one grain is still a heap. (Premise 2)
 Conclusion: 1 grain of sand is a heap.

Reversed version: 1 grain is 1 grain.
 2 grains is 2 grains.
 What number of grains becomes a heap?

I am asking not **when** simplicity turns into complexity—there is no answer—but **how** it happens.

I propose the following hypothetical twofold **principle of simplicity**:

1. **Spontaneous origin of simple systems is probable.** ⁶
2. **Complex systems spontaneously originate from simple systems by a sequence of simple steps.**

This kind of reasoning has a counterpart in the method of complete mathematical induction and in recursive functions.

Example: Long molecules of nucleic acids and proteins, as well as polymers in general, are synthesized in organisms by repeating the same simple steps with relatively simple blocks and operations. ⁷

Here the term **spontaneous** means: without a participation of human or divine mind. I apply the same term to the evolutionary origin of cognition. The term *spontaneous* does not apply either to newborns immersed into human environment, nor to robots designed

⁶ It is not so simple. For example, sodium spontaneously burns in chlorine, $2 \text{ Na} + \text{Cl}_2 \rightarrow 2 \text{ NaCl}$, but it is impossible to do it without a chemist's participation. Somebody must bring the two elements in contact. A quantum system is a better example—but not perfect.

⁷ There is a chicken-or egg discussion about the beginning of life. I believe, life started with polyphosphoric acids and was kept off equilibrium by tidal and diurnal cycles.

by human mind. Spontaneous is anything that has nothing to do with human mind or, as I would put it differently, **mind-sterile**. Artificial Intelligence, for example, reeks of human mind.

Unfortunately, the words *spontaneous* and *accidental* are both contaminated with human mind that sets the baseline of what is planned, regular, and unavoidable. I would rather get used to *mind-sterile*. Not the *mindless*, indeed. There are only two mind-sterile media that I know: the blind chance generated by microscopic physical processes and the unbending macroscopic regularity of the solar system. In a way, human civilization is the drive to control—i.e., contaminate—blind chance. We corrupt it with order and it fights back.

Any design of the mind that contains an algorithm is already contaminated with human mind and cannot serve as a model of spontaneous emergence.

Is it possible to create sterile artificial conditions for a natural intelligence? The closest but still distant approximation could be creating the **simplest** artificial mind, just two cells, and letting it evolve to the human level by the principle of **simplicity** in animal or human simulated or duplicated environment by a **simple** recursive algorithm. The problem is that the mind will need not just a body, but a company of peers. This is so-o-o-o complex but maybe doable. I think that Ulf Grenander's GOLEM (in *A Calculus of Ideas*) was the first step in this direction. Some starting elements of my approach can be found in [complexity](#) : the content of an empty mind can be filled with ideas by an extremely simple procedure based on the concept of novelty.⁸ My main idea is: forget the algorithms, let "it" live its own life and play the game of chance, win a new bone in its own skeleton, pay the loss by death, and have a history.

PART TWO: EMERGENCE OF COMPLEXITY

In this section I will try to dehumanize the model of emergence of cognition by the disinfectant of randomness for as much as it humanly (oops!) possible.

Let us consider the process of turning a grain of cognitive sand into a heap, step by step. It will take some page space, but in the end I will compress the symbolism to letter "h"

⁸ [Pattern Chemistry of Thought and Speech and their Hypothetical Ancestor](#) and [Molecules and Thoughts](#).

as an ideogram for “combinatorial branching” with the main **I** and secondary **7** branches: **h**.

STEP 1. POINTS AND LINES

I start with a set of receptive **points** open to the stimuli of the external world. The simplest system of representing the world consists of one **point** capable of being in two states. I take a more complex but still simple case of a four point system for representing external world.

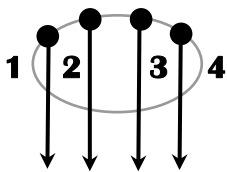


Figure 1.
Points and lines

My own representation is by no means formal and rigorous. In Pattern Theory a visual representation of structure consists only of **points** (generators) and **lines** (bonds), although a generator can have its own structure. I am describing a sloppy vague template to be deformed and hardened into something more formal, consistent, and abstract. At this point it is not really necessary.

Figure 1 shows an assembly of four sensitive points and four **lines**. When acted upon, the cell generates a signal traveling through a **line** portrayed by an arrow. This and subsequent figures are only **structures** (configurations), in which the nature of points and lines does not matter.

Simplicity is important for spontaneous emergence by bonding between four simplest singular points.⁹ Obviously, its lines (bonds) are only potential because there is nothing at the other end. We will come to the arrow targets later.

The four points and lines in **Figure 1** can serve as a primitive analyzer and their outputs could be used in various ways.

How can it become complex?

Obviously, it can happen by developing complexity “downstream,” so that the emerging “mind” can grow beyond singular sensitive points and represent more complex external situations. For the mind they are just combinations of singular inputs. The difference between two states of the world is combinatorial.

⁹ Probability/improbability of spontaneous emergence is, possibly, a way to define simplicity/complexity in an incomplete but pragmatic way. The weakest point of all our reasoning about mind is definitions given by another mind. Compare with [Essay 58](#).

STEP 2. COMBINATORY DERIVATION

Next, we form, top-down, combinations of signals from the primary sensitive points. We deal with three abstract operators: black circle ●, ring ○, and square ■. For example, they can mean logical operators **AND** (multiplication, $\times$), **OR** (addition, $+$) and **NOT** (negation, $-$). They can mean any other operation, not logical at all, for example, a formation of a neurophysiological contact, or a particular movement, or only its direction, or a spoken phrase.

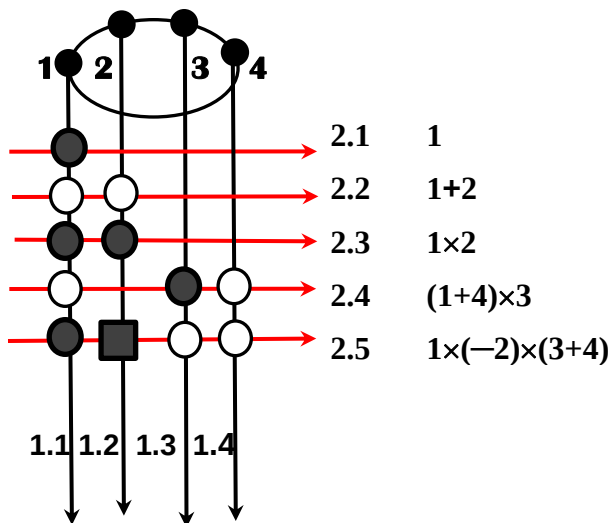


Figure 2. Combinatory derivation

In **Figure 2**, we form five horizontal lines (red arrows), numbered as 2.1 to 2.5, each corresponding to a combination of the **lines** of the first generation. Their logical meaning is in the right column. A single ● means just identity, YES, or “presence.”

An operation does not influence the function of the corresponding original (vertical black) line, which can participate in further derivations. The number (5) of derivations in **Figure 2** is arbitrary.

STEP 3. THE SCALE

Figure 3 illustrates the formation of the vertical red lines of the second **generation**, which join the array of the original black lines.

The lines of the second generation are subject to a new derivation resulting in vertical green lines of the third generation.

In order to simplify the symbolism, I use the mesh rectangle to indicate the area of combinatorial derivation without specifying the operators.

The buildup of complexity can be continued further as **alternation of stages of combination and derivation**, as well as an expansion of the primary sensitive points.

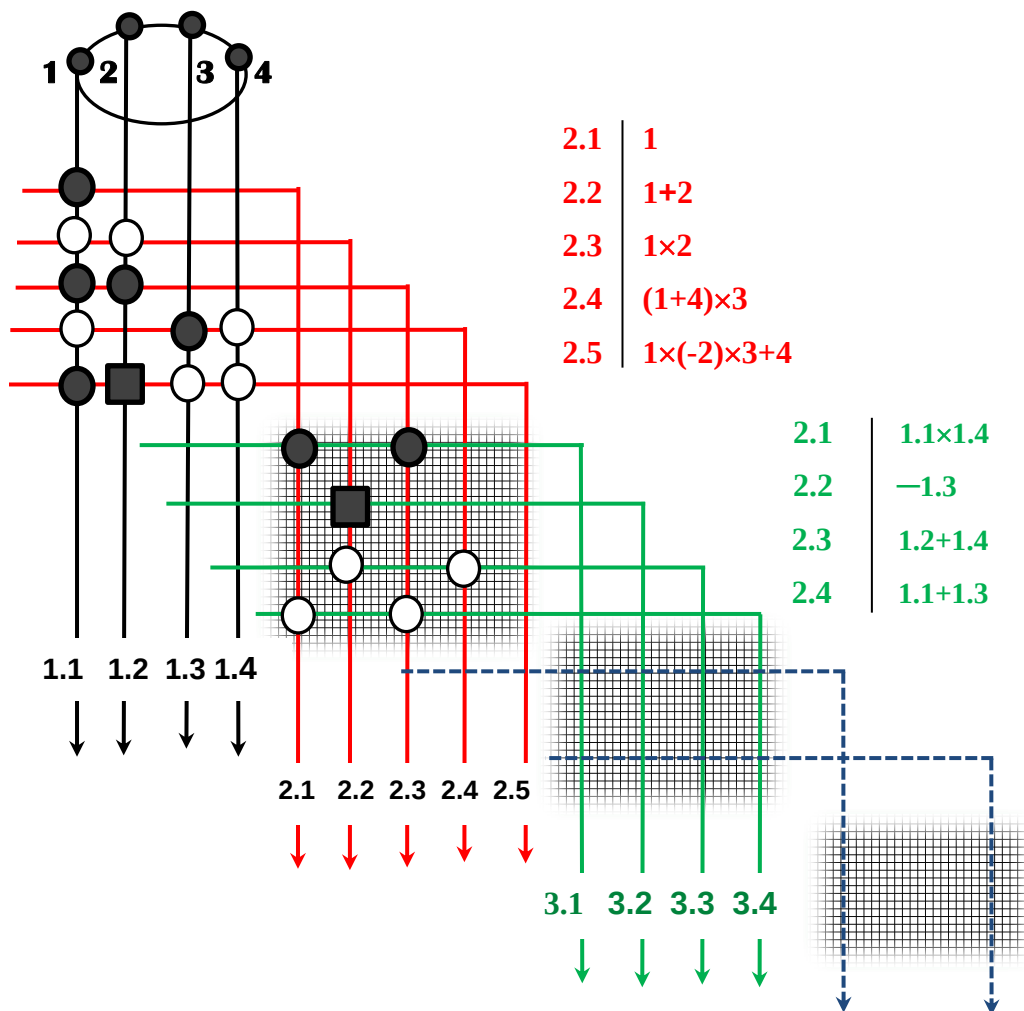


Figure 3. Expansion of the analyzer

TOWARD ULTIMATE MIND-STERILITY

The mathematical representation of the process of expansion exists: it is the scale of sets described in Bourbaki's *Theory of Sets*¹⁰ (1970), p. 383 , See **Appendix 4**.

¹⁰ Nicolas Bourbaki, *Elements of Mathematics: Theory of Sets*, Addison-Wesley, originally published by Hermann (Paris), 1968

In short, there is a basic set P . The next step of expansion includes the basic set P and all combinations of its members. The next step uses the previous set as a new base set. And so on. The scale quickly goes into combinatorial explosion. The attractiveness of the original scale of sets, however, is that no combination can be missed and the process can be completely random. But its enormity needs some filters. Here is the most mindless one: let us combine elements of the lower step **at random**, preventing some or most from entering the next step. The result will be a subset of the scale of set: a sparse scale of sets with many holes in it. The sparseness can be maintained also at random. The random death of points and lines may or may not lead to any particular direction of evolution, such as, for example, the growth of complexity. Randomness is the only disinfectant in the science of emergence.

I am moving toward the main mind-building mechanism and this is a good opportunity for a reader to exercise his or her mind and predict from where it could come.

Scale of set is a curious and even intimidating creation of the mathematical mind. There are about 150 related web pages—a microscopic volume—and a good part of them are my own pages. As soon as we imagine a real process of a random growth of some biological network, sparse scale might look tamer and more like the very ideogram of evolution.

After the principle of a step has been described, the graphic symbolism can be further simplified, as shown in **Figure 4**.

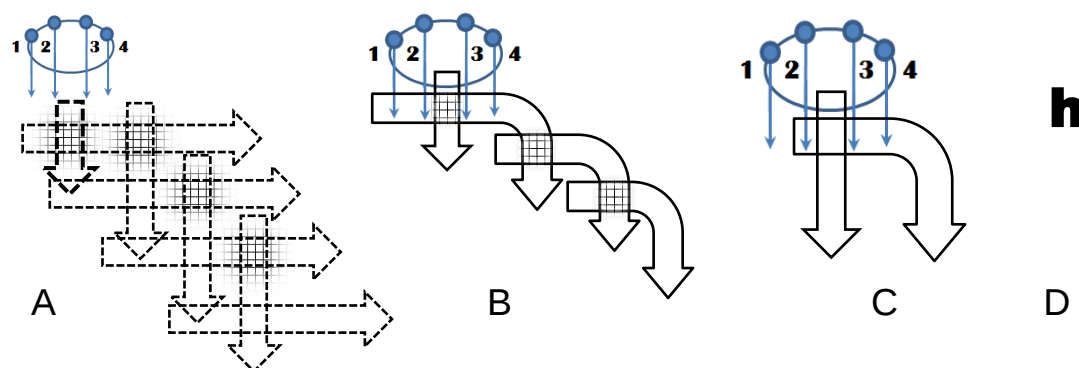


Figure 4. Compact symbolisms of derivation

The derivations do not need to be divided into sharply distinct generations. The combinations can include earlier generations in **random fashion**, as shown in **Figure 5**. We can also consider a gradual **random** dying out of much earlier generations in subsequent derivations, as in my example with American history.

Next, we allow more randomness, up to complete one, of both combinations and derivations. Randomness means exclusion of participation of a second mind because the

only thing neither mind nor computer can generate is random number, which can be a negative definition of randomness.¹¹

My last remark means that perfect randomness does not exist in any sufficiently complex system because if there is no participating mind or computer, a complex system cannot be in any of its states with equal probability. It is possible only in physical abstractions, like ideal gas. There are constraints of size on complex systems in a real world with Euclidean metrics.

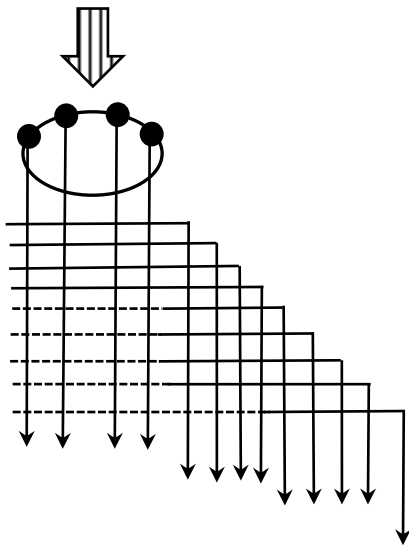


Figure 5. Abstract scale

Next step of simplification is the simplification of operations. Apparently, the absolute minimum is two, approximated as YES and NO. There is no reason to expect that nature somehow learned mathematical logic or information theory. The logic of natural systems can be fuzzy or, let me say, “analogic.” Ulf Grenander’s Pattern Theory, in my non-professional opinion, introduces probabilistic logic and thus raises a step above over the digital mainstream.

I am aware of the term “neuro-fuzzy” applied to a hybrid of fuzzy logic, with connectionist neural networks, but not more than that. I am not good at mathematics and my mind operates by similarities, connections, and images. I cannot go into this unfamiliar to me field. Instead I am giving some engineering examples in **Figure 6**.

If we attribute weights to lines and thresholds to derivations, with appropriate probability distributions, operations OR, AND, and NOT will become not random, but semi-deterministic. **Figure 6** should be understood not literally, but as analogy. The operators work by weights (**W**) and thresholds (**Th**). In some cases the outcome is clear, but when **W** and **Th** are close, the dice is rolled. The operators are so simple that each has some chances of spontaneous assembly. Nevertheless, the whole picture in **Figure 3** does not look sterile enough to me because I have designed it. It needs the final purging touch.

¹¹ While the mind is growing, its mere size can create regularity in the form of gradients, limitations, and selective enhancements. Topology of the world, the order of the previous history, and the constraints of the skull may influence the structure of the mind (not to mention brain) at any step. However, the other mind is not to be blamed for that.

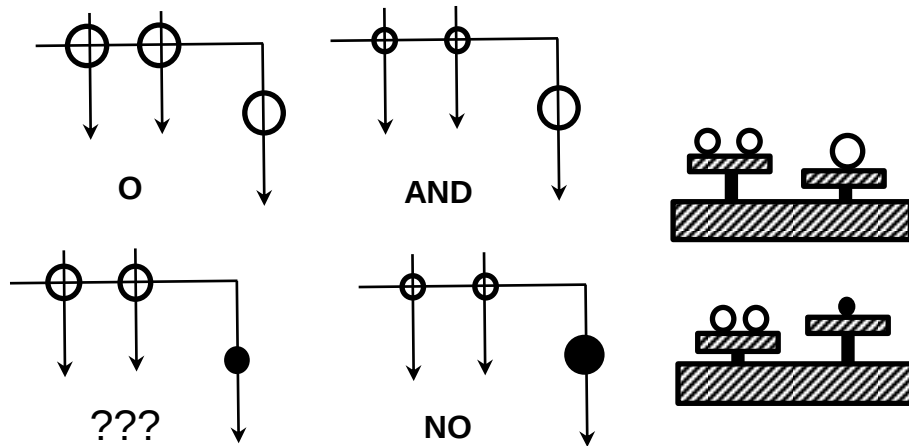


Figure 6. Analogics

HERE COMES DARWIN

The above picture has one big flaw: there is no guarantee that the expansion would go far enough because of the possibility of equilibrium between its elements and their aggregates, in other words, between simpler blocks and larger blocks of blocks. There is no law of nature which would ensure the complexification, especially because chemical—not pattern-chemical—realism predicts this kind of equilibrium for any bonding. Life and equilibrium are incompatible.

Evolution of life is unthinkable without death (or elimination in some form) as a selecting hand. Darwinian selection is the main guiding mechanism I hinted at earlier. Since the substrate if the mind is living tissue, the points and lines are no exception.

Regarding selection, we know about selection of life forms more than about selection in the evolution of the mind. There are several plucking and weeding hands capable of natural selection: diurnal and tidal cycles, daily fluctuations of temperature and humidity, seasonal cycles, and ultimately large scale random but frequent enough bouts of extinction like meteorites, volcanoes, droughts, floods, etc. These hands can rock the cradle of life—keep it off equilibrium—with the purpose of not letting it fall asleep. Note that this mechanism does not mean that all organisms move toward complexity. What it does is to make complex organisms possible. Bacteria coexist with humans.

The weeding moves each species to its niche of stability. Evolution is the survival of not the fittest but the most stable.

The Darwinian selection of thoughts seems to me a very material mechanism. All is needed for selection is memory and a constraint in the form of a limited resource. The competition for the glucose in the blood flow is the most probable mechanism of selection of thoughts. I explored some primitive models of this kind in [Molecules and Thoughts](#) and [Pattern Chemistry of Thought and Speech](#), Section *Thinking*.

PART THREE: THE h-HYPOTHESIS

I can now formulate the “h-hypothesis” (“h” as in **Figure 4D**) of the origin and evolution of the mind, which also covers the origin and evolution of life and society: the pattern tricks are the same.¹²

1. The emergence of complexity in the mind is a random reversible (not in thermodynamic sense) alternation (mutation) of combinations and derivations.
2. It starts with the simplest minds, capable of spontaneous assembly, and continues under the pressure of Darwinian selection so that only those points and lines survive that increase the stability of the mind.
3. Geological events keep the system far from equilibrium.
4. A remarkable paradoxical property of the h-hypothesis is that while the mind **expands**, its content still **converges** to most abstract and therefore useless in “street life” ideas. Mind works like a trash compactor. But this is why a scientist is, preferably, not a man from the street.
4. The mathematical representation of the process is an incomplete, mixed, torn, and sparse subset of Bourbaki’s scale of sets.

¹² Compare with: Yuri Tarnopolsky and Ulf Grenander, [History as Points and Lines](#). History is a succession of destructive and creative waves, but the products of old creative waves coexist with the most recent ones. The current coexistence of Amazonian tribes with sophisticated West European societies, 1% of super-rich with 15% poor in the USA, and the intellectual elite with the anti-Darwin and anti-science warriors in the same blessed land is the artifact of the scale-like social evolution.

5. A possible way to test the h-hypothesis is to see if simple minds, like that of *C. Elegance* can conform to it.¹³

But does *C. Elegance* have a mind?

I am a big admirer of many Douglas Hofstadter's ideas and of his poetic imagination. One among them has an immediate bearing on the above question. Douglas Hofstadter believes that any organism has a "soul," but they are very different in size, increasing from bacteria to humans.¹⁴ I agree, substituting "mind" for "soul," although I would not mind "soul" either. Have I really said that? This view of the world is very abstract, but only the high abstraction goes to the deep bottom of things.

Why can we understand the world? How can we generate new ideas? How can we successfully survive in the complex world? My answer is: it is the matter of size. Since the mind is converging by generating the more and more abstract lines coming from sensors, they shrink in number with each new level of abstraction and if relevant ones are concentrated in the mind, there are so relatively few of them that **reasoning occurs spontaneously** and fast, without any algorithm. This is the conclusion one can draw from Ulf Grenander's representation of the mind. Therefore, the "slow thinking" of the psychology of rationality is just a long sequence of fast stages: the size (quantity) matters and quantity translates into quality, as Georg Hegel told us long ago. Is America too big or too small to fail or to stand?

The chemists, who routinely deal with extremely complex structures and transformations, simplify the problem of size-related complexity in a different way. They know that a single act of chemical transformation usually involves only a few atoms in close proximity. They look only at the most probable hot spots and ignore the rest of the structure.

Whether it is a little worm or a theoretical physicist, as soon as the representation of the problem in the "mind"—or **the** mind—is reduced to a small enough size, random pattern-chemical recombinations can generate a very few alternative solutions to choose among.¹⁵

The above h-model looks like it addresses only half of the mind problem: representation of the world. There is the other part: action in response to the world.

¹³ See Nivedita Chatterjee and Sitabhra Sinha, [Understanding the mind of a worm](#) : hierarchical network structure underlying nervous system function in *C. elegans* (2008) . Authors note: "This [assortativity, a kind of hierarchy in networks] may shed light on one of the central questions in evolutionary biology that resonates strongly with the theme of this volume, namely, why did brains or central nervous systems evolve?]

¹⁴ In *I am a Strange Loop* (2007)

¹⁵ That would be a mechanism of fast thinking (Keith Stanovich, David Kahneman, Amos Tversky), but I have a bone to pick with the division of thinking into fast and slow, see [Pattern chemistry of rationality](#) (Essay 58).

Although I am not going to discuss it here, in **Figure 6** I reproduce Figure 54.4 from my [The New and the Different](#) (1996, Chapter 54, The Mathematical Mind, p. 413), where more detail about the analyzer and synthesizer can be found.

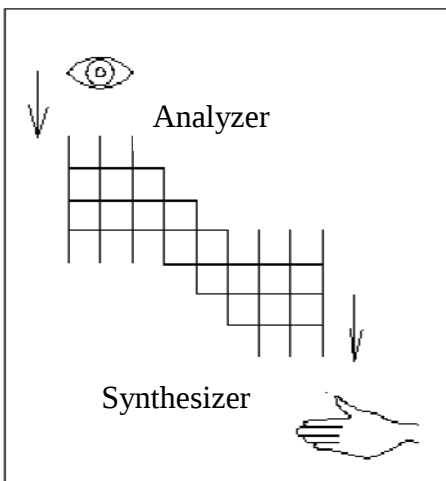


Figure 6 . Analyzer and synthesizer.

The core of the mind, obviously, is the realm of ideas, not of point sensations that come from the outside. The trash compactor leaves predominantly higher levels of the scale, which are less numerous and are not anchored at particular sensitive cells of the organism. Some of lower level ideas hide in the subconscious and probably not all of them can be expressed in words.

This is how the analyzer works. Next question, what to do with its output? This information must have some use and the arrows should find their targets.

The second part of the mind, the synthesizer, is a diverging scale, anti-symmetric to the analyzer. It uses the compacted processed information and converts it into elementary responses of the cells, mostly of muscles, including speech, writing, and work, as well as automatic reflexes poorly controlled by the mind. It is diverging because the number of both sensors and effectors is large as compared with most abstract ideas, although this is only an uneducated guess.

The synthesizer accepts the output of the converging “h-analyzer ” and in an IF—THEN manner converts it into the behavior in the same way as in any stage of derivation. What is different, this derivation is diverging into an array of elementary physical movements or their series. For a sufficiently complex organism, a large number of incoming configurations is analyzed into a smaller number of categories and the result used as a signal for a hierarchy of large number of outgoing elementary movements. The derivation matrix is the standard block for both.

Having once invented a trick, nature uses it again and again as pattern in very different areas.

SO, HOW DOES THE MIND REALLY WORK?

We can better understand an exsystem by complementing **its history** with the **history of its understanding**. In this regard, I would like to compare the h-hypothesis with the two perfectly indisputable leading ideas presented by Steven Pinker in his *How the Mind Works*. My understanding of both, however, could be disputed.

First idea: the mind works because there is a correspondence between ideas, their symbols, and changes in the state of matter. The Turing machine and its incarnations process information (“ideas”) by manipulating symbols and physically writing and erasing them. Brain is the “matter” of the mind. I believe I follow this principle by wiring up the scale and avoiding the mathematical symbolism.

Second idea: the mind, like life in general and other functions of our bodies, emerged in the process of the natural selection of replicators, which is the modern way to say “Darwinism.” This is my favorite idea, too, regarding mind, but from a different angle.

My first remark is that any Turing machine must have a set of instructions or “reflexes,” as Steven Pinker notes. No picture of mind, however, will be complete without the explanation how this set comes to existence without the pre-existing condition of another human mind present. Now, how does that other mind work? Turing machine had Turing. Whom do we have?



M.C. Escher

My second remark is that since natural selection of replicators is the cardinal pattern of evolution, it would be natural to generalize it further and apply not just to life forms and memes¹⁶ but to thoughts in the individual mind. This is the core of my approach. In my computer simulations I used a particular model of competition for a limited resource: Manfred Eigen's concept of molecular evolution¹⁷. Ulf Grenander's GOLEM, however, is more general because it uses casting a random number to determine the winning thought. In my view, casting a random number is a competition for a limited resource of the sum of all probabilities (always 1). It has one winner. But what happens with thoughts next in line of decreasing probabilities? I see them living in the subconscious, the less probable the deeper.



I reproduce in **Figure 7** a figure (Figure 8) from [*The Three Little Pigs : Chemistry of language acquisition*](#).

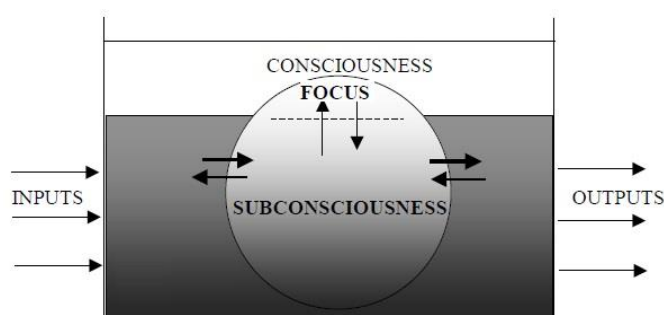


Figure 7. Consciousness as the winning configuration in competition for a limited resource

ANSWER

Mind is an exystem. It works by maintaining a probability distribution of competing thoughts. The winner (or a few leaders) rise to the consciousness, the rest descend to the subconscious in order of decreasing probabilities. The probability distribution at a particular moment depends on the distribution at the preceding moment. Thus, the question “Whom do we have?” creates—slow or fast—a distribution which pushes up into the consciousness this answer. (I confess, it was ready long before). Until there is a computer that thrives on randomness and can be foolish, careless, forgetful, and deceitful, there is still a gap between thinking machines and human mind.

¹⁶ For example, the medieval memes spread by some right wing Republican congressmen.

¹⁷ M. Eigen, Selforganization of Matter and the Evolution of Biological Macromolecules, *Die Naturwissenschaften*, **58**, 465-522 (1971).

CONCLUSION

My not so hidden agenda with this essay was to show that the cardinal problem of the origin of complexity, mind and life included, may have a simple solution. Such mundane property as the size of structure plays a role in cognition as large as the size of a company or just a mountain of money in economy. For thinking, however, the smaller, the better. This is all hypothetical, of course.

I suspect that h-hypothesis could be relevant for the origin, structure, and function of DNA (which is, ultimately, a kind of Mother Nature's long and slow cooked thought), but this area is too big and too distant for me. Can anybody try? Here it is in the nutshell: the origin of DNA can be described using h-hypothesis. This would explain the role of the DNA Dark Matter (former "junk") in the chromosomes by its history.

Pattern Theory, as mathematics in general, does not know borders between domains of the world and domains of our knowledge about it. As simplicity is partly measured by size, I am satisfied with these 18 pages (if with anything at all).

Pattern Theory is the bridge between sciences and humanities. I believe my free-wheeling style naturally fits the borderless world.

"I approve this message" is humming in my mind, induced by the din of the election campaign, a show based not on the Aristotelian TRUE/FALSE logic, but on the weights and thresholds expressed in decibels of insanity.¹⁸ It is just another step of combinations and derivations, some of which are potentially fatal for nations.



¹⁸ See Pattern chemistry of 2012 Elections , [Essay 57](#)

APPENDIX 1

MAIN SOURCES FOR PATTERN THEORY

Ulf Grenander, *General Pattern Theory: A Mathematical Study of Regular Structures*, Oxford University Press, 1994.

Ulf Grenander, *Elements of Pattern Theory*, The Johns Hopkins University Press, 1996.

Ulf Grenander, *A Calculus of Ideas: A Mathematical Study of Human Thought*, World Scientific Pub Co Inc. , 2012.

Numerous sites on the Web.

PATTERN THEORY AND PATTERN CHEMISTRY:

Yuri Tarnopolsky, COMPLEXITY, <http://spirospero.net/complexity.html>

In particular:

Molecules and Thoughts: Pattern Complexity and Evolution in Chemical Systems and the Mind

The Three Little Pigs : Chemistry of language acquisition

Pattern Chemistry of Thought and Speech and their Hypothetical Ancestor

TIKKI TIKKI TEMBO: The Chemistry of Protolanguage

Also:

Essay 57. THE FEW AND THE MANY

Essay 58. ALL RATIONAL MINDS ARE ALIKE; EACH IRRATIONAL MIND IS RATIONAL IN ITS OWN WAY. Pattern chemistry of rationality

APPENDIX 2

The idea of this essay is dated by 1956-1957, when I was a student of chemistry at Kharkov Polytechnic Institute. It was the second oldest technical university in the former Russian Empire. Its “institute” means the same as the “institute” in MIT.

It was the times of Nikita Khrushchev’s “thaw,” the end of Stalinism, and the end of prohibition on “bourgeois” pseudo-science of cybernetics. The first ever public lectures on cybernetics, organized by Yuri Sokolovsky, a professor of the local academy of military communications, attracted a lot of attention. He also ran a seminar at my Institute for the staff of the department of Electrical Technology and I was the only (future) chemist there and, probably, the only student. The problem for discussion was “the reading automaton,” a device for recognizing text, now known as OCR, optical character recognition. I offered an idea and gave a presentation which did not cause any stir.

My “reading automaton” would translate combinations of non-trivial elements of the letter, like the ends and the elbow of letter L or the sharp angles and the ends of letter N, into the name of the letter using the principle of the scale of sets. I still do not know if it would work, but I saw that the principle was much more universal than character recognition.¹⁹

Norbert Wiener’s *Cybernetics*, published in Russian in 1958, impressed me as much as the chemical experiments, which I saw at the age of 13, that made me a chemist. I began to read more on mathematical logic, set theory, and discovered the scale of sets.

After decades of watching development of computer and cognitive sciences, staying in contact with Ulf Grenander for many years, and watching his work on Pattern Theory of the mind, I still believe that my idea makes sense because it is mind-sterile—a kind of an oxymoronic pun. This is why *mindless* is not a good term.

¹⁹ Yuri Tarnopolsky, [The New and The Different](#)

APPENDIX 3

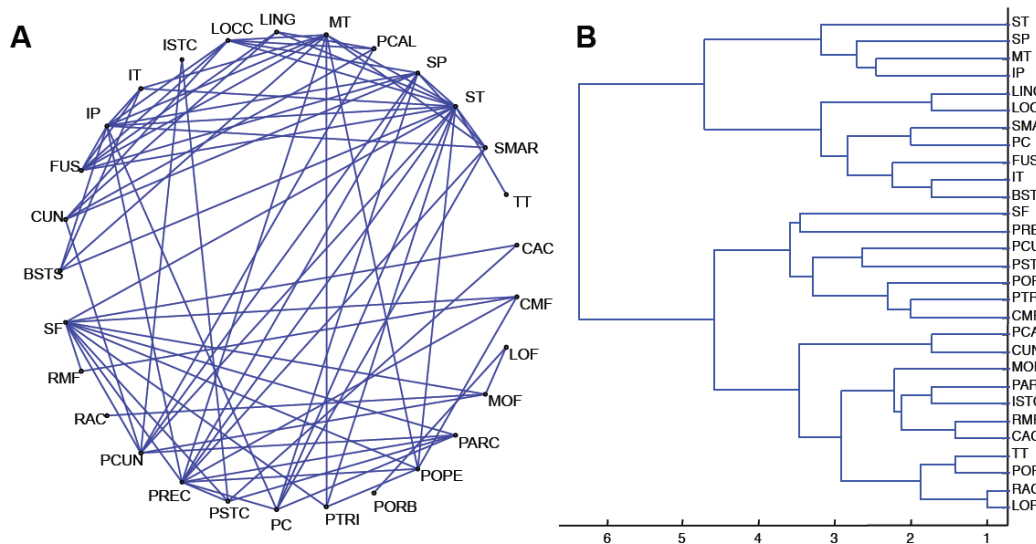


Figure 8 Connectivity in the brain

Figure 8 is reproduced from: Marcus Kaiser, [A tutorial in connectome analysis](#): Topological and spatial features of brain networks, *NeuroImage*, Volume 57, Issue 3, 1 August 2011, Pages 892-907 , [Fig.4](#). Marcus Kaiser uses this [source](#).

Abbreviations label some of anatomical subregions of the brain. The cortex has the 2D topography and distances between small regions widely differ. Part **A** shows the **topology** of connections between the areas regardless of the distance. Part **B** (dendrogram) reflects the **metric distance** between the subregions. For example, MT and IP are close, SP is somewhat farther from both. Areas ST down to BSTS are far from areas SF down to LOF. Both show further division.

I see a very oblique—less oblique from the pattern view—confirmation of the principle of combinatory derivation under constraints of natural selection in the detailed (a lot of subtleties!) research of connectivity in *C. elegans*., **Figure 9** is reproduced from: Varshney LR, Chen BL, Paniagua E, Hall DH, Chklovskii DB (2011) [Structural Properties of the *Caenorhabditis elegans* Neuronal Network](#). PLoS Comput Biol 7(2): e1001066. doi:10.1371/journal.pcbi.1001066.

Since I am not a professional, my understanding and interpretation of this work could be grossly wrong.

The map is an extremely detailed 90% complete connectivity (**topological** adjacency) matrix of two systems of contacts between neurons: electrical (blue circles) and chemical (red points) with the size of the mark reflecting the number of contacts per neuron.

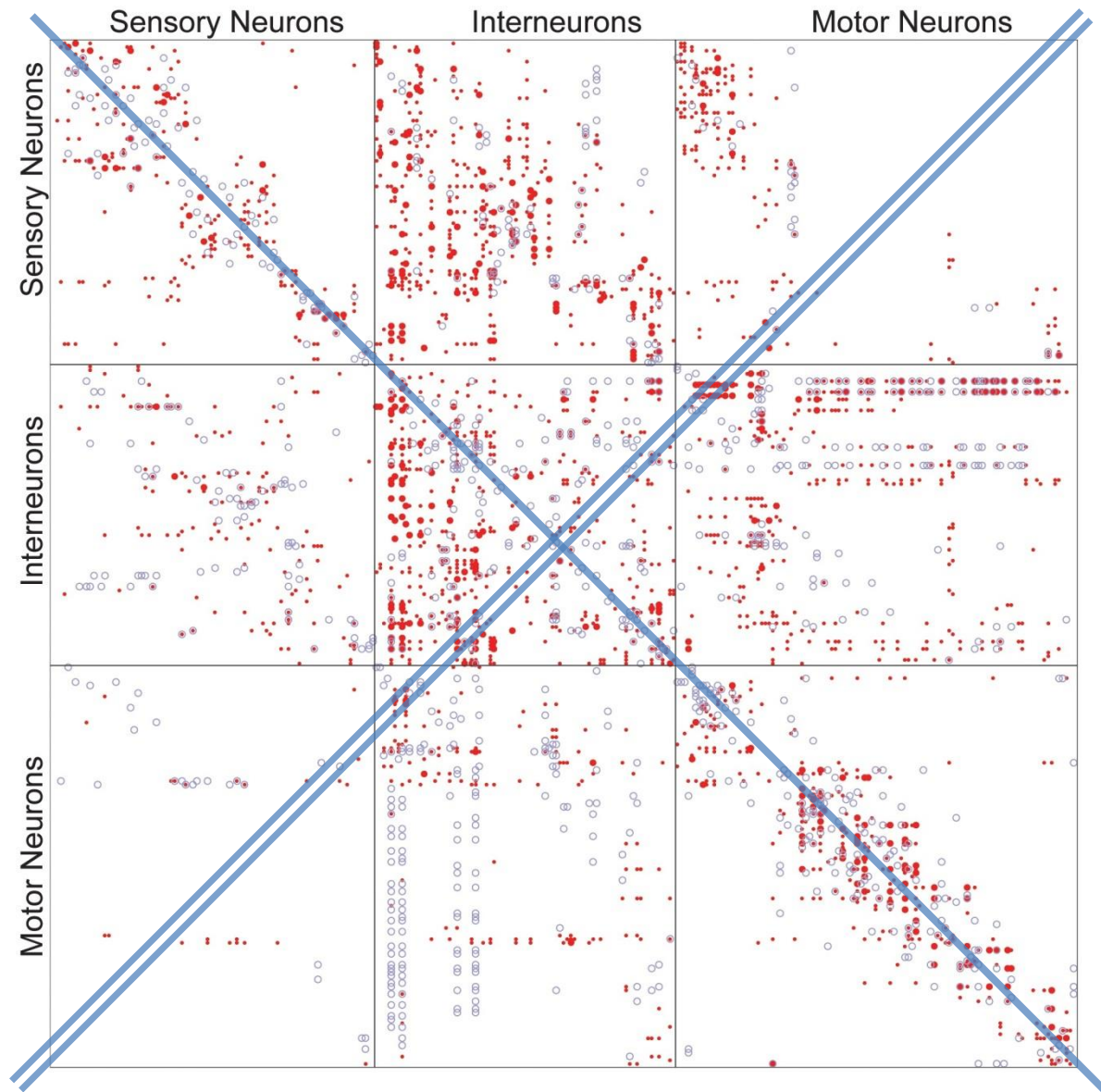


Figure 9. Adjacency matrices for the gap junction network (blue circles) and the chemical synapse network (red points) with neurons grouped by category (sensory neurons, interneurons, motor neurons). See [original work](#), Fig.1, for details, most of which I do not touch. I added double “slash” (/) and normal “backslash” (\) diagonals.

The important property of the map is that the neurons in each group—sensory, interneurons, and motor—are enumerated in **topographical** order from head to tail. The map, therefore, reflects not only topology, but also **topography**. The matrices for sensory and motor groups are visibly sparser and are populated along the diagonal. It

means that the neurons there make contacts mostly with close **topographic** neighbors. The interneurons, on the contrary, form a rich “small world” network. The communication between head and tail, naturally, is extremely limited. I want to draw attention to the “slash” (/) diagonal of the matrix. To me it shows the pattern similarity of the overall organization of the nervous system as result of their evolution: the sensory and motor neurons interact predominately with topographic neighbors. Analyzer and synthesizer are anti-symmetric. Their type of grid-like continuity, with topographic diversity, reproduces the organization of the continuous Euclidean external space, whether as object of perception or as the subject of action. The central nervous system, a descendant of its precursor in the worm, is where the two bundles intersect into a tight topological knot of a “near-complete” graph. This is the place where dreams and fantasies are born.

The authors of the cited work noted in *Discussion*: “Several statistical properties [in particular, synapse multiplicity distribution] of the *C. elegans* network are similar to those of the mammalian cortex.”

Hypothetically, the “combinatory derivation,” or scale, for which the term B-evolution (B for Bourbaki) could also be appropriate, explains how the mind evolves gradually, wavy, and smoothly, the way the little worm wriggles on videos posted by its well-deserved worshippers.

APPENDIX 4

8. SCALES OF SETS. STRUCTURES

1. Given, for example, three *distinct* sets E, F, G, we may form other sets from them by taking their sets of subsets, or by forming the product of one of them by itself, or again by forming the product of two of them taken in a certain order. In this way we obtain *twelve* new sets. If we add these to the three original sets E, F, G, we may repeat the same operations on these fifteen sets, omitting those which give us sets already obtained; and so on. In general, any one of the sets obtained by this procedure (according to an explicit

scheme) is said to belong to the *scale of sets on E, F, G as base*.

.....

Thus being given a certain number of elements of sets in a scale, relations between generic elements of these sets, and mappings of subsets of certain of these sets into others, all comes down in the final analysis to being given a *single element* of one of the sets in the scale.

FROM: Bourbaki, N. (1968). *Elements of Mathematics: Theory of Sets*. Reading, Mass.: Addison-Wesley.

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